Final Design Report: Infrasonic Wildfire Detection

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Senior Capstone Design

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ABSTRACT

Team FireSense (David DePaolis, Christopher Salcido, Nicholas Shipp, Luke Woods) have continued the work of designing an Infrasonic Wildfire Detection device throughout the 2021-2022 academic year by reducing the electronics size and cost, as well as developing a new payload delivery system. They achieved these goals by replacing the full-size development board with smaller packages and combining them onto a single printed circuit board, and by researching and prototyping a samara leaf (maple/helicopter seed) payload to protect the electronics during deployment. These changes allow for finer control over the layout and components of both the electronics and the payload, while reducing the cost and size of both aspects of the project. Team FireSense was able to evaluate and verify all components of the electronics function and were able to reliably repeat reduced velocity delivery of the payload.

The final size of the printed circuit board and components was 86.6140mm long by 45.7200mm wide by around 15mm thick, weighing 35.48g with a final cost of $32 (36% reduction in cost per unit from previous years). The final payload assembly (electronics included) was 480.58mm long by 158.74mm wide by 19.35mm tall in the shape of a samara leaf, transitioning to autorotation flight after 25ft, and falling with an angle of attack of 29.3° at a velocity of 1.83m/s.

BACKGROUND

As the past several years have shown us, wildfires have become an increasingly prevalent threat to homes and businesses across the country. However, surveying expansive wilderness areas is impractical, and current detection methods are constrained to sight and smell of smoke (from Firewatch towers on the ground) or from a combination of visible and infrared imaging from satellites. Research at the University of Idaho in the College of Natural Resources revealed that wildfires reliably give off a characteristic low-frequency signal (infrasound, below 20Hz) that is not often found in nature.

To augment the current wildfire detection methods, previous capstone teams at the University of Idaho have constructed an Infrasonic Wildfire Detection sensor. The first year identified all the necessary components needed to create this sensor and designed a low-pass filter to isolate the infrasound so that an inexpensive microphone could be used for signal acquisition. The second team (2020-2021) developed a point-to-point mesh network communications system, so that we can deploy a network of sensors over an area and have them communicate with each other. This would be used for relaying the information that one node receives back to a central location where the data could be processed and acted upon.

This technology could be deployed over a large area of land, which may be at a heightened risk for wildfires, and remain there listening for wildfires through the course of a fire season. This would serve as an additional method of detection and could increase the speed at which existing fire control infrastructure can respond to a natural disaster.

PROBLEM DEFINITION

Stanley Solutions presented the project to us with the goal of finding and developing an aspect of the project we would be enthusiastic about improving (with slight emphasis on payload drop testing). After reviewing the past teams' work on the Infrasonic Wildfire Detection device, FireSense identified six areas that could be improved: Troubleshoot PCB (microphone signal acquisition), Condense Circuitry, Battery/Life and Power, Networking Communications, Signal Identification/Analysis, and Payload Design/Delivery.

FireSense decided that the aspects most in need of improvement were the size and the cost of the electronics and developing a new payload delivery system. The sensor electronics handed off to team FireSense were a prefabricated development board (~$50/unit) with excess components and a large filter attached. The payload handed off to the team was a robust PVC tube enclosure with a prototype cloth parachute.

The payload is required to perform all the following:

- Survive deployment
- Establish a dynamic mesh network
- Collect infrasonic signals
- Report information to a central location

The current electronics system enclosure fits within the following:

- Length < 7in
- Diameter < 3in
- Volume < $50in^2$

The final electronics system enclosure specs will be equal to 50% or smaller than the current payload size. The wing portion of the payload will be considered different from the electronics system enclosure and will be required to fit within the same volume listed above.

The cost to build a proof-of-concept prototype shall not exceed a value of $50. The goal for the final product will be to not exceed $25 per payload device.

The following are the major Project Milestones:

1.	PRD, Value Proposition	September 23rd, 2021
2.	Project Schedule, Budget, DVP	October 7th, 2021
3.	Snapshot Day 1	October 12th, 2021
4.	Concept Design Review	November 12th, 2021
5.	Snapshot Day 2	December 3rd, 2021
6.	Engineering Release Review	February 18th, 2022
7.	Design EXPO	April 28-29th, 2022

PROJECT PLAN

Team Roles and Responsibilities

Team FireSense consisted of four members:

- David DePaolis – Electrical Engineering, Physics
- Christopher Salcido – Mechanical Engineering
- Nicholas Shipp – Computer Engineering

- Luke Woods – Mechanical Engineering

With the two paths for the project chosen (reduce PCB size/cost, and further develop payload delivery system), we split into two teams to develop these solutions in parallel.

DePaolis and Shipp would identify the necessary components for the function of the sensor according to the code that had been developed the year prior, removing the non-essential components, and condensing all the electronics into one PCB. DePaolis reviewed the first team's work on the filter system, identified surface mount technology alternatives to through hole parts, and performed rudimentary power testing of the PCB. Shipp identified the required electronic components and designed all versions of the PCB, as well as manufactured the test/prototype circuit boards.

Salcido and Woods would research, design, and prototype a samara leaf (maple/helicopter seed) inspired payload delivery system to house and protect the electronics during the initial drop and deployment in the field. Salcido designed the battery holders that were implemented into the body of the payload, assembled all testing models, and performed drop testing and impact analysis. Woods designed all versions of the full payload, manufactured all constituent components of the payload, performed drop testing and impact analysis, and finalized all team presentations and reports.

Salcido conducted oversight of the team's budget. Both Salcido and Woods created Team Agendas. All team members took Meeting Minutes throughout the year.

Project Schedule

The following figure illustrates a condensed version of the team's project schedule. A fully detailed version of the schedule can be found in the appendix.

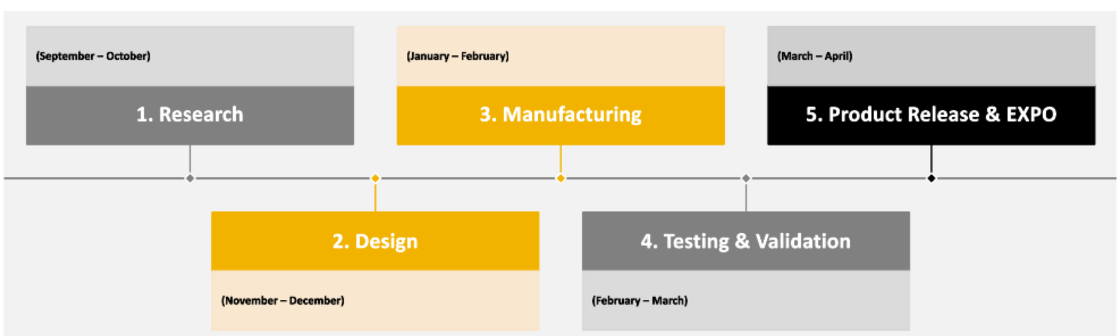


Figure 1: Condensed Project Schedule, Main Sections and Dates

CONCEPTS CONSIDERED

PCB Redesign

DePaolis and Shipp revisited the electronics design from previous teams and found several areas to further reduce the size, cost, and system power consumption with the project's long-term goal of being mass produced in mind. For size and cost, the focus was re-selection of essential components only, use of surface mount equivalents for through-hole components, and PCB layout optimizations. For system power, the focus was on lighter and more environmentally friendly battery alternatives.

Size/Cost Reduction

Previous teams used a bulky and expensive prefabricated development board. While this was beneficial for proof-of-concept work, further size and cost reductions needed to be made. Fire Sense considered stripping the electronic components to the bare minimum to get away from the development board. In doing so the system could then be moved onto a single PCB. Surface mount components (SMT) provide an attractive alternative to through hole components (THT) because of their reduced size, and only interacting with a single layer of the PCB. However, it should be noted that SMT components are more difficult to handle and verify with testing once soldered.

PCB layout optimizations were a constant consideration for Fire Sense throughout the iterative design process. Reducing the size of the electronics in turn reduces the size of the entire payload, as the wing is proportional in size to that of the electronics. When choosing design suites, there were two main options, both equally valid: Autodesk Eagle or KiCad. When choosing manufacturers, two main options present themselves: Commercial Manufacturers or the In-House PCB Shop. Commercial Manufacturers have the benefit of being able to reliably produce boards with fine trace width/spacing, including a solder mask and silkscreen, but take a considerable amount of time to be delivered. The in-house PCB shop on campus is limited to two copper layers with no solder mask or silkscreen, and trace width/spacing no smaller than 0.5mm. The turn-around time is only a couple of days, however, which lends itself to rapid prototyping. It should also be noted that plated through holes must be requested ahead of time and take an extra day to manufacture but simplifies soldering of components and increases the reliability of the circuit.

System Power

The development board used by previous teams sported a battery holder for a Lithium-Ion 18650 cell. While this is a common and low-cost option, it is large and by no means the most environmentally friendly option. Fire Sense researched several battery types (Liquid-Air, Lithium-Air, and Zinc-Air) prioritizing options that were small, low weight, and had an inert chemical makeup.

Further considerations were also proposed to extend the battery life of the system. Additional battery cells can be added to a modular power bank to increase capacity, but weight distribution of the payload will need to be re-considered. Additionally, integrating a solar panel element into the wing of the payload could be used to recoup some of the power consumed during normal operation.

Payload Design/Delivery

Salcido and Woods reviewed the progress past teams had made on the drop deployment for the payload and found there was ample room for further development. They reviewed different deployment methods and determined the following four solution paths: Parachute Deployment, Blunt Force Delivery, Autorotation Motors, Samara Leaf.

Parachute Deployment

Fire Sense could have reduced the velocity of payload by using the Drag equation to design a parachute.

$$D = \frac{1}{2} \cdot A_p \cdot \rho \cdot V^2$$

Drag Equation

Where D is drag, A_p is the area of the desired parachute design, ρ is air density, and V is velocity. To find the mathematical effectiveness of different parachute designs before conducting drop testing, a velocity would be found depending on the weight of the payload and the area of the parachute. Parachutes come in three basic shapes, each with different flight characteristics.

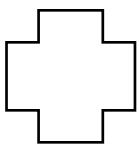


Figure 2: Cross Parachute

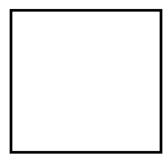


Figure 3: Square Parachute

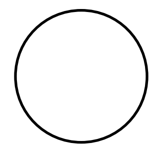


Figure 4: Circle Parachute

The cross shape is easy to build, it has a low drag coefficient, and it is more stable as it falls. The square parachute is the easiest to build, it has the most intermediate drag coefficient, but it is the least stable as it falls. The circle is slightly more difficult to build, it has the highest drag coefficient, and is the most unstable as it falls.

There were drawbacks of the parachute design. When dropped into the wilderness without the guarantee of support from technicians, the parachutes could get caught in trees which would be advantageous for signal propagation, but they could interfere with the local environment. Parachutes also have far more points of failure than the following options, as well as requiring more assembly and care when packing.

Blunt Force Delivery

The payload would need to be robust enough that it does not break the internal components as it impacts the ground. One idea for accounting for this is to cushion the components inside the payload to mitigate the force of the impact. A payload that falls at terminal velocity must also be directed aerodynamically to land in a desired orientation (antenna and microphone facing up). Falling at terminal velocity would also create a hazard for wildlife that may happen to be underneath.

Autorotation

Rotor blades can spin from the relative wind coming from under them, as opposed to from a motor, and continue to generate lift. This concept lends itself to a falling payload that needs to reduce its velocity to protect its components. The main concern team FireSense had was the moving parts. Because the rotors must be able to spin freely, this introduced a major point of failure for the payload. Another consideration that would have to be made for this design is reducing the amount of friction between the payload body and the rotor blades. This could be avoided by fixing the blades to the body and allowing the whole payload to rotate, which leads us into the final solution we researched, the samara leaf.

Samara Leaf

A samara leaf (or maple/helicopter seed) functions utilizing the same principle of autorotation as described above. As the seeds fall, part of the wing catches the wind and forces the wing to begin spinning. The spinning motion causes the rest of the wind to generate lift for the seed. This reduces its terminal velocity by converting part of it into rotational velocity and lift. The advantages of this type of payload are numerous.

Team Fire Sense's research showed that the maple seed (and its flight characteristics) can be reliably reproduced in a lab setting (Wind Dispersal of Natural and Biomimetic Maple Samaras). The seed itself is also "stable against wind disturbance and is insensitive to initial conditions" (IOP Science) because it will always rotate to enter dart-mode before transitioning to autorotation (Wind Dispersal of Natural and Biomimetic Maple Samaras). The seeds are also chiral (IOP Science), meaning they will always land with one side facing up, which is ideal when accounting for the placement of the antenna and microphone. The most advantageous factor of the samara leaf is that it is a single mechanical body, reducing the points of failure and allowing for simpler manufacturing.

CONCEPT SELECTION

Electronics Design

DePaolis and Shipp decided to pursue several of the PCB redesign considerations listed above. To move the electronics onto a single PCB, components were reselected so that only necessary components remained. These components included: an ESP32 development board for system processing, a GPS chip for node location, a transceiver for message relaying, a voltage regulator for a stable power rail, and passive components for signal filtering. Links to specific component datasheets are included in the appendix at the end of this report.

When designing the PCB layout, Shipp used KiCad (v6.0) as this was our project sponsor's (Joe Stanley) preferred design suite. The program is intuitive and well documented online, with several footprint libraries included. SnapEDA also proved useful for sourcing PCB footprints for components not included in KiCad's native libraries. To facilitate multiple prototypes, the In-House PCB shop was used over other Commercial Manufacturers as the turn-around time is much quicker on campus.

After researching the batteries used previously, and several other battery alternatives, the decision was made to proceed using Zi-Air 675 cells. These batteries provide us with marginally improved energy density as compared to the previously used Li-Ion cells, while also greatly reducing the size and weight of the power system. Zi-Air cells also have an inert chemical makeup which helps to minimize the environmental impact of our payloads.

Payload Design/Delivery

Salcido and Woods pursued the benefits of the samara leaf method of delivery, sighting its straightforward design and rapid reproducibility, both in manufacturing and simulation. Modeling both the Blunt Force Delivery Method and the Parachute method had been produced by the previous year's team in their initial payload design. To investigate the samara leaf, Salcido assembled a balsa wood and tissue paper model at the conclusion of Fall Semester 2021 to demonstrate the design without rapid manufacturing.

After reviewing the previous team's payload work and considering the benefits of each design, the decision was made to develop rapid prototypes of the samara leaf.

Payload Material Selection

A material selection index (Materials Selection in Mechanical Design) was developed with the help of Dr. Matthew Swenson to judge materials based on their performance characteristics. A material index is built considering an object's geometry and integrating in an equation that includes the material's desired quality (strength, density, etc.). Dr Swenson and the book recommended the following Strength over Density index for picking materials for the composite design of a wing because it would find materials maximizing strength and minimizing density.

$$M = \frac{\sigma^{\frac{2}{3}}}{\rho}$$

Figure 5: Strength over Density calculation

Once the Material Index was found, it was applied to a material selection graph representing Strength over density. It was decided to model physical samara models out of PLA and wood because both had similar strength to density ratios for keeping their shape during moments of light force impact but will not be so heavy that they would affect flight characteristics unfavorably.

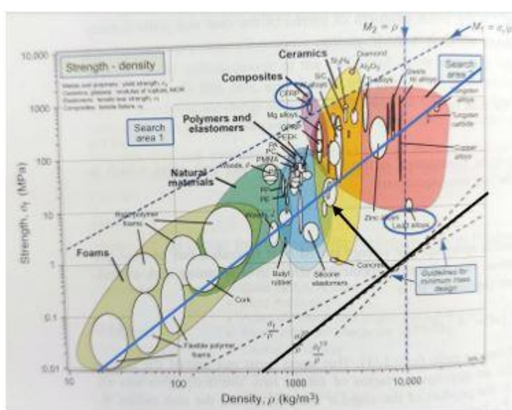


Figure 6: Material Index for Strength over density

SYSTEM ARCHITECTURE

Electronics Design

The electronics system was comprised of three main parts: the battery array, the signal filter, and the communications system.

The battery array needed to supply a consistent 3.3V rail to the rest of the system; this was achieved with a set of 3 Zi-Air cells that were placed in series and connected to a voltage regulator. The regulator was required due to the variation in the cells' nominal voltage levels (1.45V down to 1.15V per cell) with typical discharge. This modular design allowed for additional sets of battery cells to be added in parallel, thereby increasing the overall capacity of the power bank. Our design currently includes two sets of battery cells (6 individual Zi-Air cells).

The signal filter needed to listen to its surroundings and identify if a nearby wildfire was emitting its characteristic low-frequency signals. To achieve this, a simple 2-pin electret microphone was employed in tandem with a low-pass Chebyshev filter to detect sounds from the environment and sharply attenuate signals above the infrasonic focus. The filter was configured with typical RC filter passive components and op-amp ICs (LM358s) to boost the mic input, validate the signal, and boost the output to readable voltage levels. Transitioning from a through-hole technology solution to a primarily surface-mount configuration permitted significant size reductions which are exhibited in the figures below.

The processing/transmission system is needed to create and send messages when the signal filter detects a wildfire and relay messages from other nodes that are also transmitting. To achieve end, the ESP32 development board will acquire the node location from the GPS chip and process it to create an initialization message to be sent via the on-board transceiver through the mesh network. Nodes on the mesh network will carry this information to a central location/master node wherein the signal could be processed and displayed to the operator.

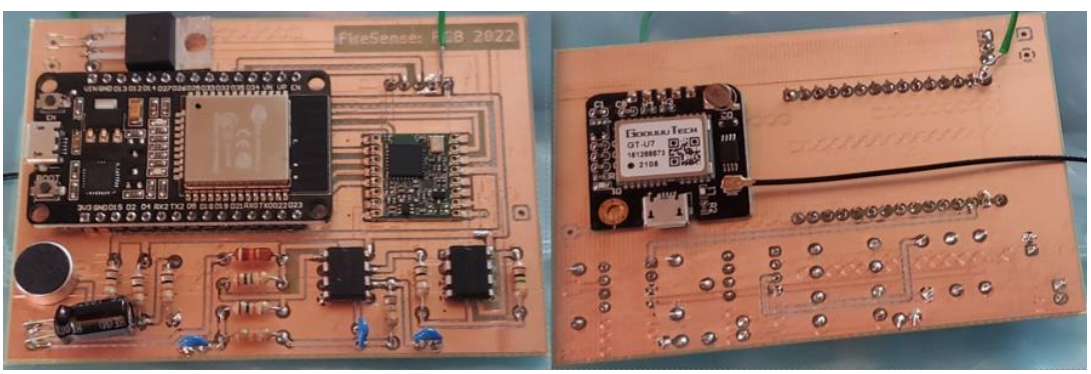


Figure 7: PCB Version 1 Including Through Hole Components

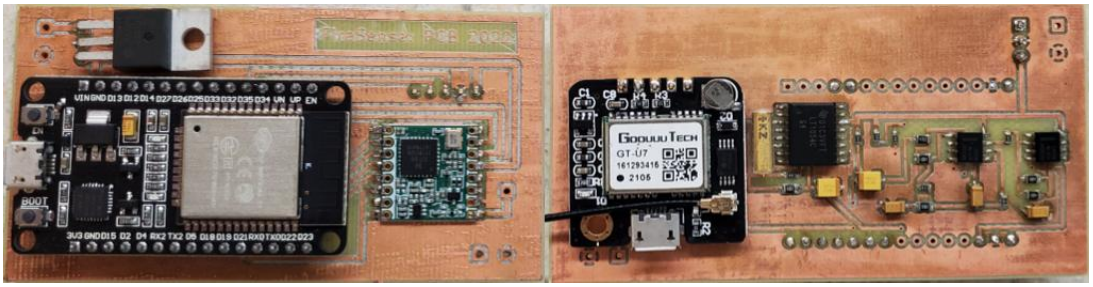


Figure 8: PCB Version 2 Including Surface Mount Components

Payload Design

The samara leaf has two distinctive features: a thick and heavy nut, and a large thin wing. The large nut lends itself perfectly to housing all the electrical components for the sensor, while the large thin wing can be manufactured around the size of the nut to achieve the desired flight characteristics. In addition to the rationale of the previous section for the composite payload materials selected, the use of PLA plastic and wood for manufacturing the main components allows us great flexibility in the design.

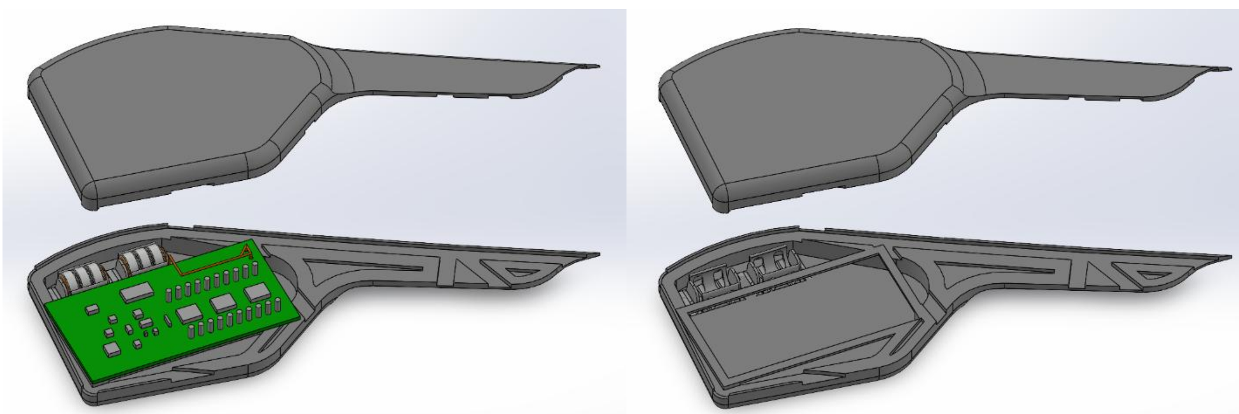


Figure 9: Images of Samara Payload Housing with and without components

Team FireSense utilized 3D printing of the PLA plastic to manufacture the nut of the payload. This allowed them to customize the design of the payload nut housing to fit exactly around the components included, while maintaining the ability to easily alter the design as they continued their work. Manufacturing the housing using 3D printing provided a much faster turnaround time than machining would, providing the advantage of being able to manufacture and evaluate prototypes early. The payload housing is dimensioned to fit tightly around the condensed PCB while maintaining the shape of the samara leaf found in nature. The interior of the housing is primarily filled by the condensed PCB and its components, with supports to hold it in place during deployment. The payload nut housing is 116.11mm by 91.79mm by 19.35mm with a wall thickness between 1 and 6.5mm at its thinnest and thickest. The tail extends out an additional 102.21mm, is on average 21.23mm wide while tapering in and out and is 3.28mm thick. There is an inlay set around the outer edge of the payload with the exact depth and contouring of the wing skeleton to hold it in place.

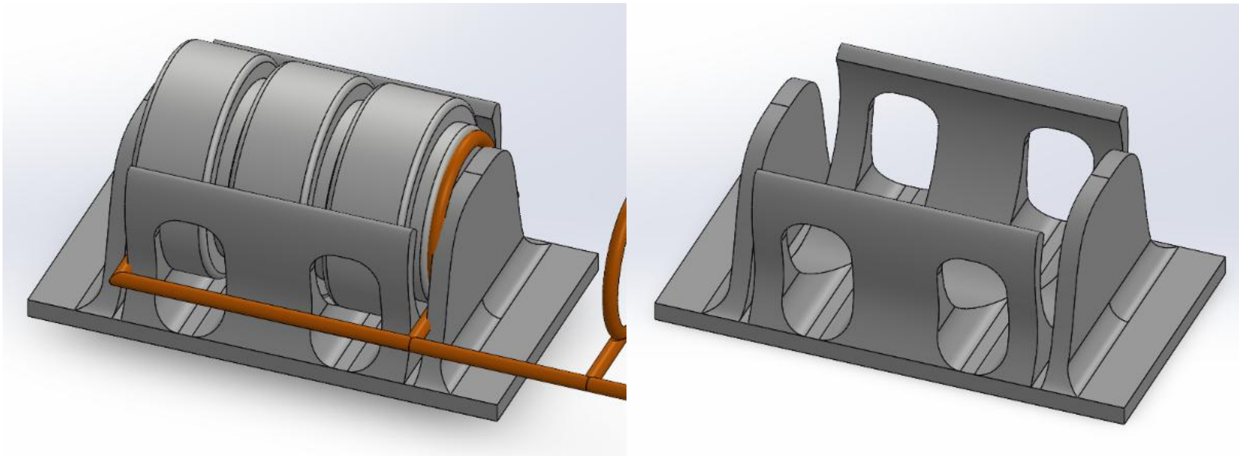


Figure 10: Image of Battery Holders with and without components

Included in the housing are two battery holders designed to contain a set of three Zi-Air 675 Cells in series. These allow a user to snap in and out batteries for deployment while holding the batteries in place and pressing them against the wire connected to the PCB's power lines. The walls surrounding the batteries are 0.75mm thick, the inner diameter of the walls is equivalent to the outer diameter of the Zi-Air Cells, and the walls rise 25° above the horizontal midplane. The end walls are 1mm thick and are spaced 0.5mm away from the ends of the series of batteries to provide room for the power line wires to contact the batteries.

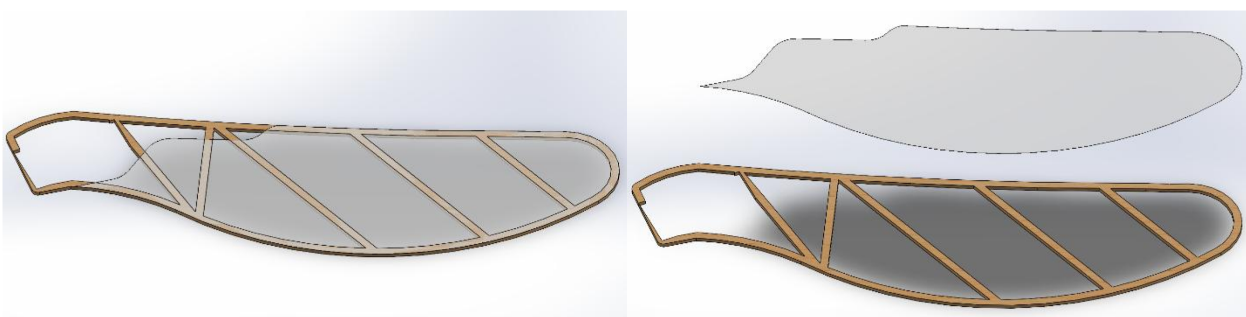


Figure 11: Images of wing assembly with and without skin

The wing of the payload is comprised of a laser cut birch wood skeleton with a visqueen polyethylene plastic sheeting to span the empty space in the wing. Team FireSense chose to laser cut the wing skeleton for the payload because it afforded a similar degree of customizability and rapid manufacturability in design. We selected birch wood to laser cut because it is an easy-to-use hardwood, readily available, and produces consistent results when laser cut. The wing skeleton has an overall dimension of 479.58mm by 157.73 by the birch wood stock thickness of 1/8in, following the contour of the nut housing as well as the contour of a typical samara leaf sound in nature. There are struts along the length of the wing every 71.68mm to provide rigidity to the wing. The width of the cutout parts is 6.35mm in all places, and the thickness of the birch wood is 1/8in.

The wing skin was applied with a hot glue to bond with the birch wood skeleton and cut to the outer edges of the skeleton. The full assembly was sealed in the same manner to provide a functioning prototype for drop testing.

DESIGN EVALUATION

Electronics Design

Filter Testing

Testing the filter was divided into multiple stages, accounting for more subdivisions of the design in each experiment, starting from the output to the dev board. Each stage was validated individually with an oscilloscope and an arbitrary waveform generator, the latter programmed according to the transient simulations from the designing phase of the project. Foremost, tests were conducted directly on the filter, with and without the inverting amplification; the oscilloscope was connected to read the voltage level on the development board's pin, and the waveform generator was connected to represent the output of the pre-amplification circuit following microphone on the schematic (Appendix.) Readings from the oscilloscope were compared to the SPICE simulations to validate the filtering capabilities, programming only two points per decade for ease of testing. Afterward, the experimental scope was expanded to include the pre-amplification circuit, substituting the microphone with the arbitrary waveform generator and proceeding as previously. Filter behaviors were considered functional if they were "reasonably proportional to" the simulated results as simulations were conducted under significantly different conditions. Smaller, irregular signals from the microphone, unique layout capacitances and inconsistent variations in the values of passive components were, at this scale, inclined to disrupt results. Example oscilloscope readings are shown below:

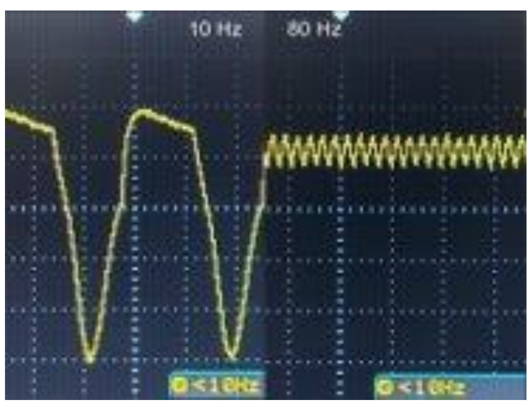


Figure 12: Attenuation, less than -7 dB from 10Hz to 80Hz

DePaolis expected attenuation at this frequency to be sharper than –20 dB, or less than 1% of the input amplitude. While inconclusive, this result demonstrated that the filter was properly attenuating higher frequencies, or more specifically, showed expected behavior.

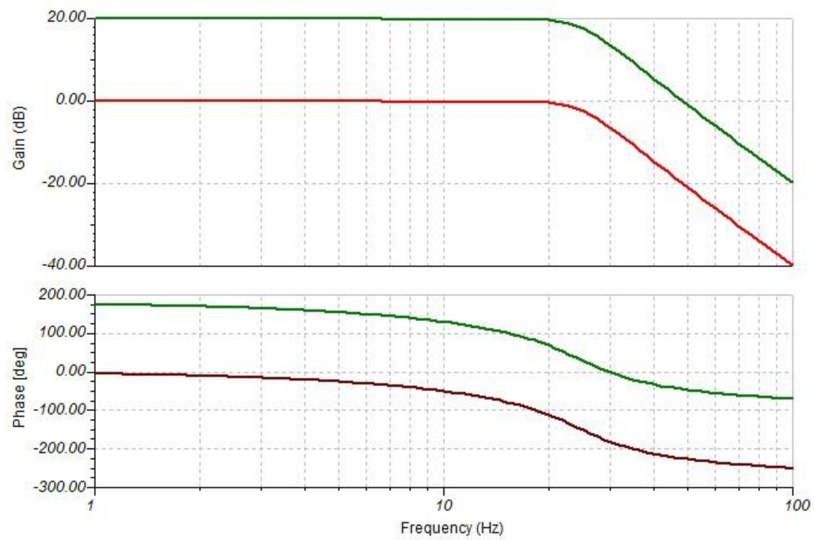


Figure 13: Simulated, perfect attenuation results from filter (in appendix)

Size Reduction

Shipp made multiple PCB layout optimizations to reduce the overall size of the electronics system. DePaolis ensured that the reconfigurations, changes in track weights, and reduced component sizes did not compromise any of the PCB connections via simple inspections with multimeters. Since the schematics were pre-simulated in SPICE, a nodal analysis was employed to find node voltages, and some noteworthy node voltages like the filter power rails were compared. Power connections were verified with LEDs on specific components on the board.

Payload Design/Delivery

Salcido and Woods determined that physical prototyping would save time and be inexpensive. The team was concerned with proving the scalability of the wing because the governing principles behind the Samara leaf design seemed to suggest that a samara leaf of any size would fly a desired flight profile so long as the weight distribution is correctly placed. Since the density of air was not going to change from testing small models to the large ones, it was just as feasible that the wings would not fly in the desired manner once scaled to be too large.

1/5 Scale Model Testing

Woods designed four wing shapes to evaluate their flight characteristics at 1/5 scale the size of the expected full assembly. Each shape was skinned with yellow tissue paper and were designed to fit a universal nut printed from PLA. The models were taken to a 14ft balcony on the South side of the University of Idaho IRIC building and dropped in cloudy conditions, gusting at 5 mph. Shape A (Appendix) was modeled by designing over a picture of a natural samara leaf. Since this shape was the most found in nature, the other wings were adjusted to come off this original shape. Shape A's flight characteristics were the most inherently neutral regarding its dart-mode flight time and its rotational stability. Shape B (Appendix) featured a more emphasized droop designed to catch more air as the leaf fell. Drop tests of Shape B successfully demonstrated that a large wing surface area would encourage both the rotational flight phase and the coverage of more distance as the wing would stay airborne for longer. Shape C (Appendix) fell straight down in the lateral axis with minimal spinning, as did Shape D (Appendix) which spun flat but fell fast. Shape A's most neutral and reliable flight characteristics were achieved by attaching a small lead fishing wight to wing spar closest to the nut with a piece of tape.

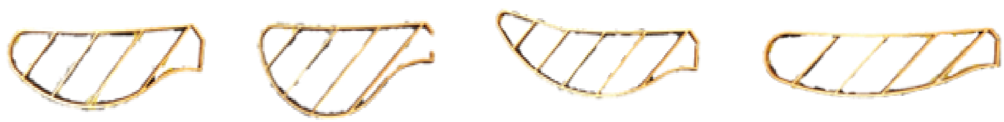


Figure 14: Samara Shapes (left to right) A, B, C, and D

1/2 Scale Model Testing

Shape A was scaled up to 1/2 the size of the predicted full-scale model and taken to the 3rd floor of the Atrium in the University of Idaho IRIC building, 32ft above the ground. The 1/2 scale model was dropped several times as Salcido and Woods recorded the flight characteristics and experimented with the effects of weight distribution by attaching small fishing weights to distinct areas of the design. The most neutral flight characteristics were achieved when fishing weights were taped to the inside of the nut. Video footage was taken of each drop test in slow-motion to create stills for rotation angle estimation and velocity calculation. The 1/2 scale Samara model reliably fell with a fall angle of 6°, started spinning after falling 5ft, and its calculated fall velocity was 1.78m/s.

Figure 15: Display of Samara ½ scale with space to insert lead weights

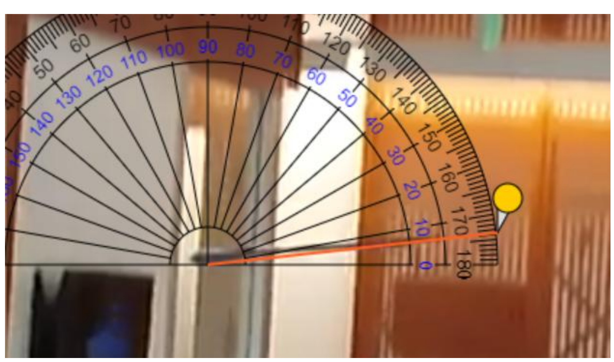


Figure 16: Fall angle Approximation of ½ Scale Model

Full Scale Model Testing

Full Scale Model drop testing took place at the University of Idaho atrium in the same fashion as the 1/2 scale model, testing the validity of the weight distribution practices learned for the half-scale model. A new wing nut was designed for the full-scale PCB, and it featured a larger wing area. No fall angle data was recorded because the design failed to autorotate due to what was believed to be incorrect weight distribution. Woods recreated the 1/2 scale model shape to fit the SMT PCB and drop testing yielded favorable results. The heavier payload fell at 29.3°, started spinning after falling approximately 14ft, and fell at a terminal velocity of 1.83m/s.

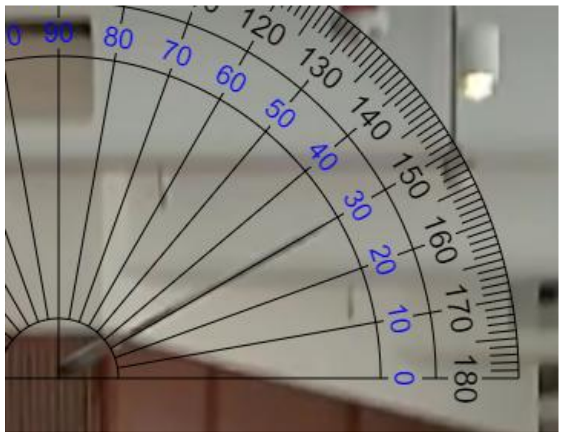


Figure 17: Fall Angle Approximation of Full-Scale Model

FUTURE WORK

Electronics

Possible directions for future teams regarding the electronics system are listed below.

The following teams should aim to further reduce the size of the PCB by using a bare chip (ESP32) design and outsourcing a finalized board layout to a commercial manufacturer. This will lead to a smaller and lighter electronics system, which in turn would lead to a smaller payload delivery device. This endeavor will take another year of research and manufacturing; however, it is crucial to the reduction in price and size of the sensor.

Signal acquisition, identification, and interpretation testing needs to be performed. Past teams did not find adequate time to evaluate and record the performance of the microphone and filter combination. Tests and Analysis should be performed to determine the range and accuracy (finetune ~20 Hz target) of the microphone, as well as test the accuracy of the microphone and filter combination. This investigation should take half a semester, and the cost should be near zero.

In the far future, combining the knowledge of the sensor accuracy and the flight characteristics of the payload, teams should be able to optimize the density (number of sensors/area) of Infrasonic Wildfire Detection devices needed to accurately scan the area being monitored. This should consider the size of the area, as well as the number of obstacles present and their size. This endeavor should take a year of development, once other aspects of the project are completed, and should have near to zero cost.

During engineering EXPO, one attendee suggested implementing a sonic sensor for game tracking/migration patterns. This would take a year's worth of work for proper integration, and the cost should remain small.

Payload Design

Possible directions for future teams regarding the payload design are listed below.

Investigate how changing the form and weighting of the samara payload affects its flight characteristics. Future teams can characterize what different physical properties have on the flight; examples may include does a thicker leading-edge lead to a faster transition to autorotation, how does weighting placement affect the flight characteristics? The investigation into characterizing these effects would take one to two more years of research and development, however, it would not cost much as the supplies to manufacture a single full sized payload cost around $2-3.

Research materials for weatherproofing and sealing and implement a procedure for sealing the payload. Team FireSense used a 3M Hot Meld Adhesive Glue to seal the payload together. Future teams should investigate a watertight sealant and create a procedure for application that covers all points of liquid ingress. Special consideration should be made for the possibility of moisture wicking into the payload through the wood wing skeleton. This should only take a semester of research and application, with the cost staying just above the price of sealants.

Future teams should investigate the feasibility of creating a 3D wing skeleton? If the time to produce a wing shape is still efficient, this could make the wing portion of the payload thinner and lighter. FireSense experimented with Loctite plastic bonder to permanently join separate 3D printed parts. Research from Wind Dispersal of Natural and Biomimetic Maple Samaras paper stated a 30:1 nut-to-wing weight ratio was "heuristically providing the desired autorotation properties."

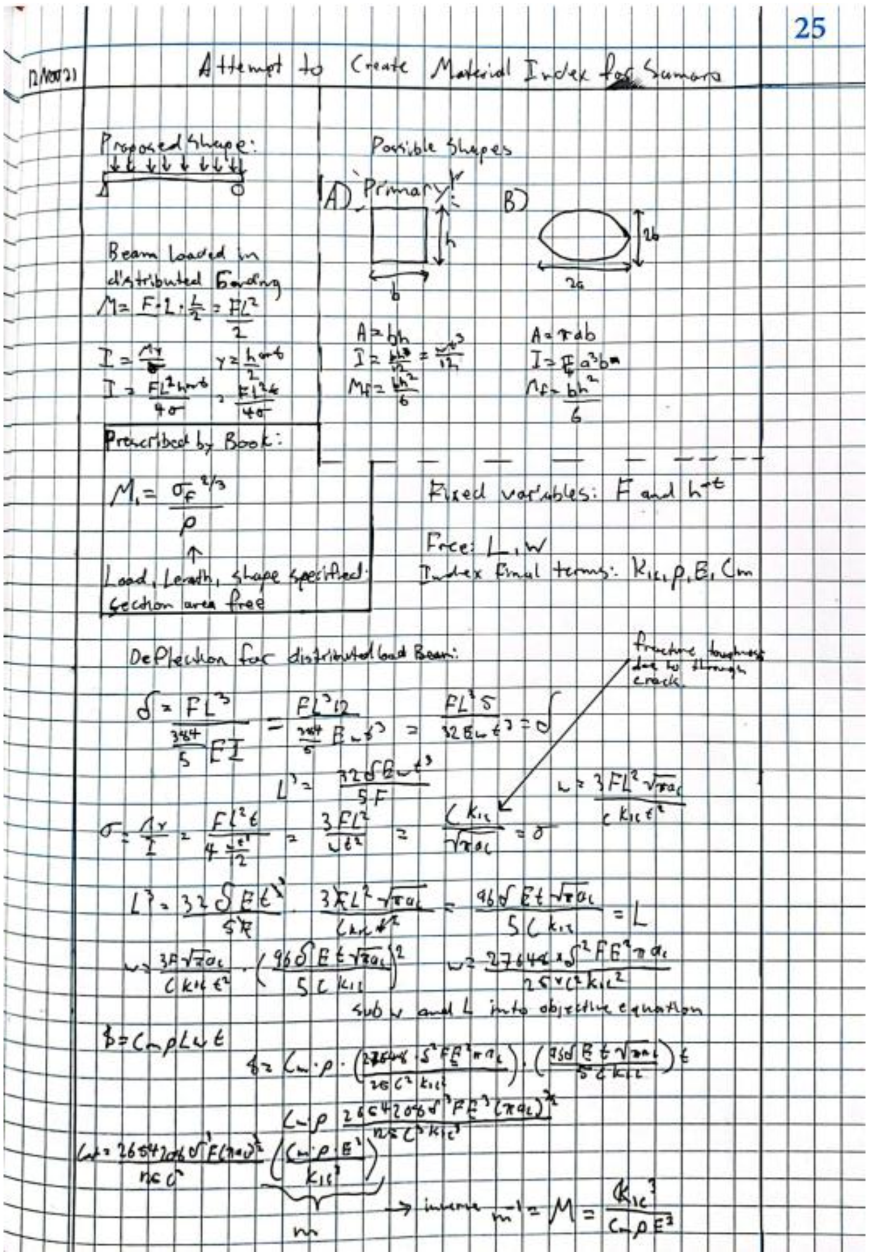
Further research should be made into environmentally friendly materials to reduce any adverse effects that might stem from leaving the payload out in nature. Teams should consider the interaction between the payload and its components with the local flora and fauna. This research should take a year and would cost only the price of the materials used to manufacture new payloads.

APPENDICES

Calculations and Drawings

Material Selection

Book Reference: Materials Selection in Mechanical Design by Michael F. Ashby 5th Edition



Integration of Material Selection Index referencing techniques from Materials Selection in Mechanical Design by Michael F. Ashby

$$M = \frac{\sigma^{\frac{2}{3}}}{\rho}$$

Figure 7: Strength over Density calculation

Parachute Information

https://www.webpages.uidaho.edu/dl2/on_target/tv.htm

$$D = \frac{1}{2} \cdot A_p \cdot \rho \cdot V^2$$

Drag Equation

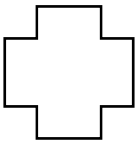


Figure 1 Cross Parachute

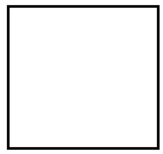


Figure 2 Square Parachute

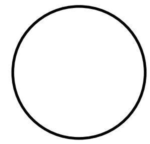


Figure 3 Circle Parachute

Autorotation Information

https://www.faasafety.gov/gslac/alc/course_content_popup.aspx?cID=104&sID=452#:~:text=Autorotation%20is%20the%20state%20of,event%20of%20an%20engine%20failure.

Low Flying Aircraft Information

https://www.faa.gov/about/office_org/field_offices/fsdo/lgb/local_more/media/FAA_Guide_to_Low-Flying_Aircraft.pdf

Samara Wing Shapes

Figure 9 Samara Shape A

Figure 8 Samara Shape B

Figure 10 Samara Shape D

Figure 11 Samara Shape C

Figure 12 Samara 1/5 Scale marked with A and 1/2 scale without marking.

Payload Drop Testing Calculations

Slow-Motion video was taken on a Samsung Galaxy A71 phone camera that displays video at 1/5 the speed of regular video.

1/2 Scale Model:

Rotation Angle= 6 degrees

The item fell for 30 slow-motion seconds= 6 seconds

23 seconds slow-motion, 4.6s falling in rotation

Object Height= 32 feet- 9.7536 meters

Object Rotation Height= 27 feet= 8.2 m

Rotation Falling Velocity= 1.78 m/s

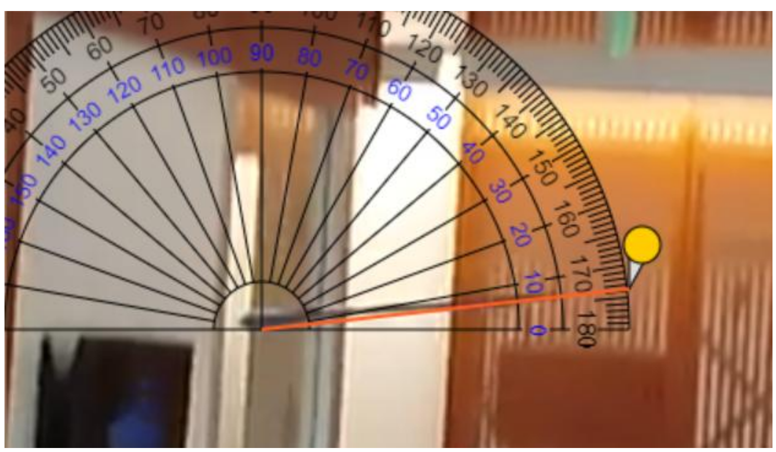


Figure 13: 1/2 Scale Samara Fall Angle Approximation- 6°

Full Scale Model

Time to Fall: In Slow-motion (4 seconds) in x2 Samsung Galaxy S10e camera (Actual 2 Seconds)

Fall Distance spinning: 12’= 3.66m

Fall spin Velocity= 1.83 m/s

Rotation Angle: 29.3°

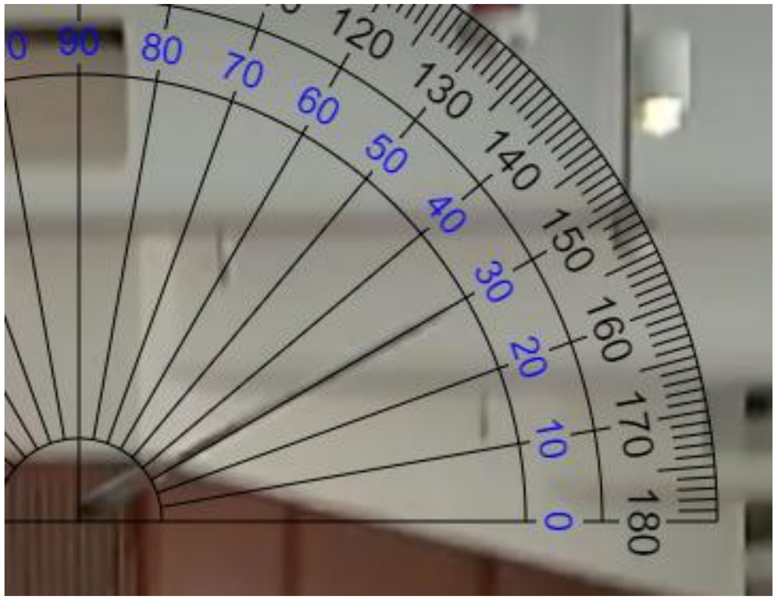


Figure 14 Samara Full Scale Fall Angle Approximation

Payload Assembly Drawing Package

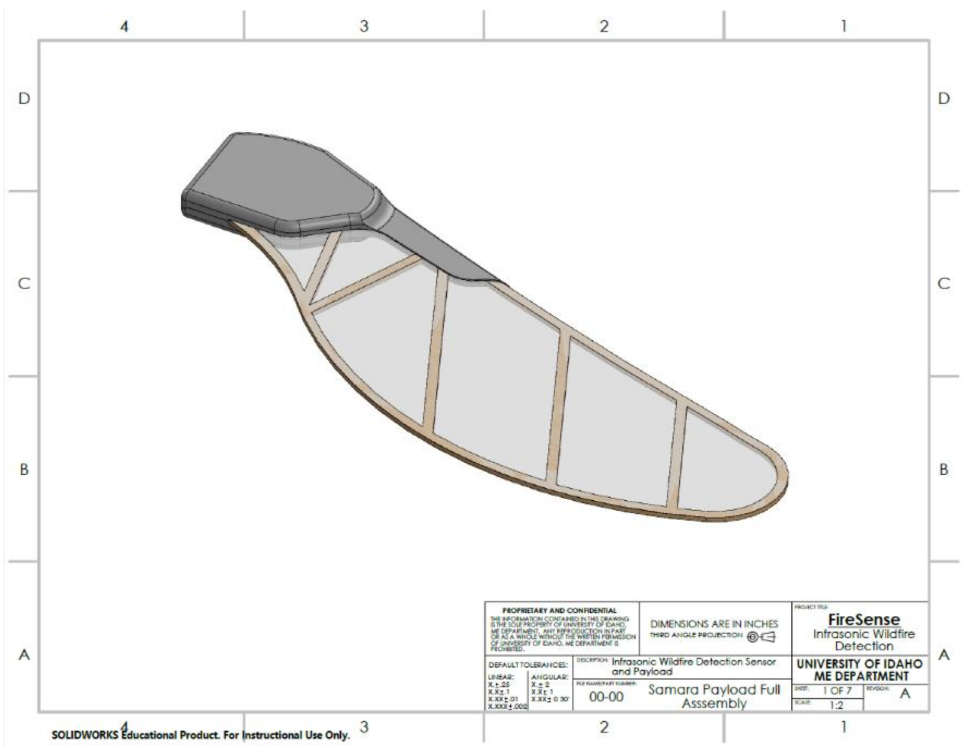


Figure 15: Technical Drawing Package Sheet 1, Full Assembly

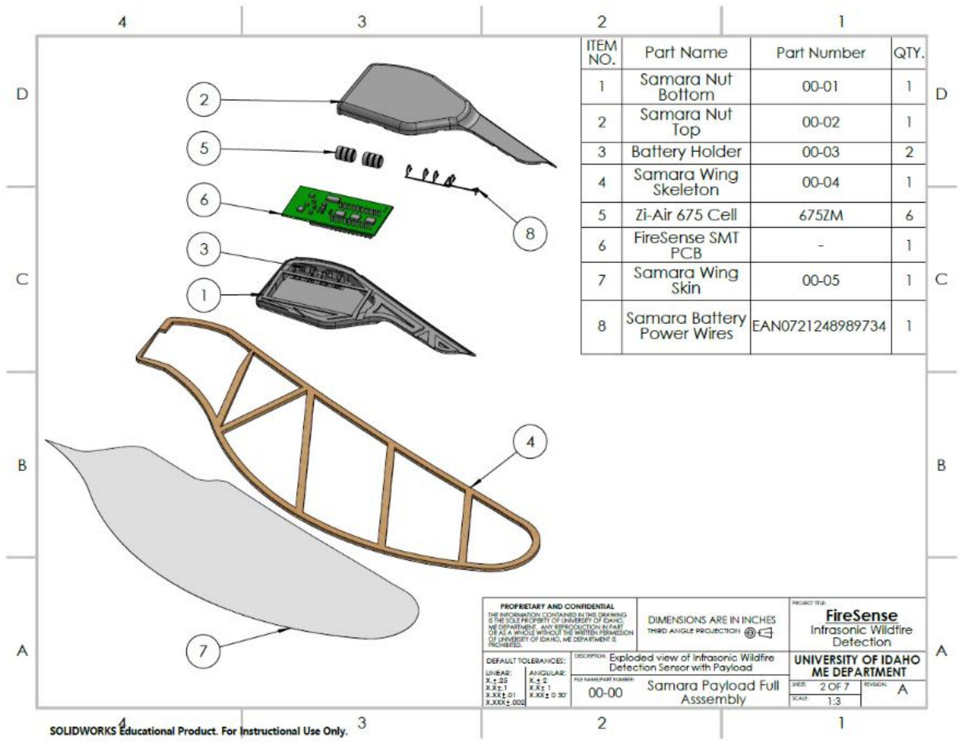


Figure 16: Technical Drawing Package Sheet 2, Exploded View

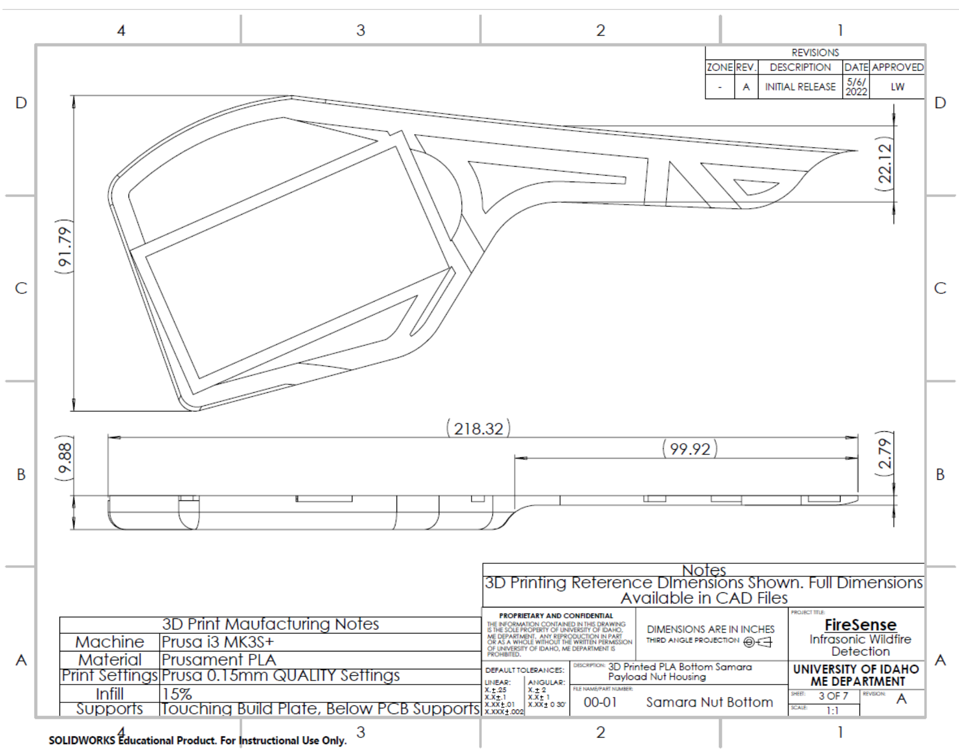


Figure 17: Technical Drawing Package Sheet 3, Samara Nut Bottom

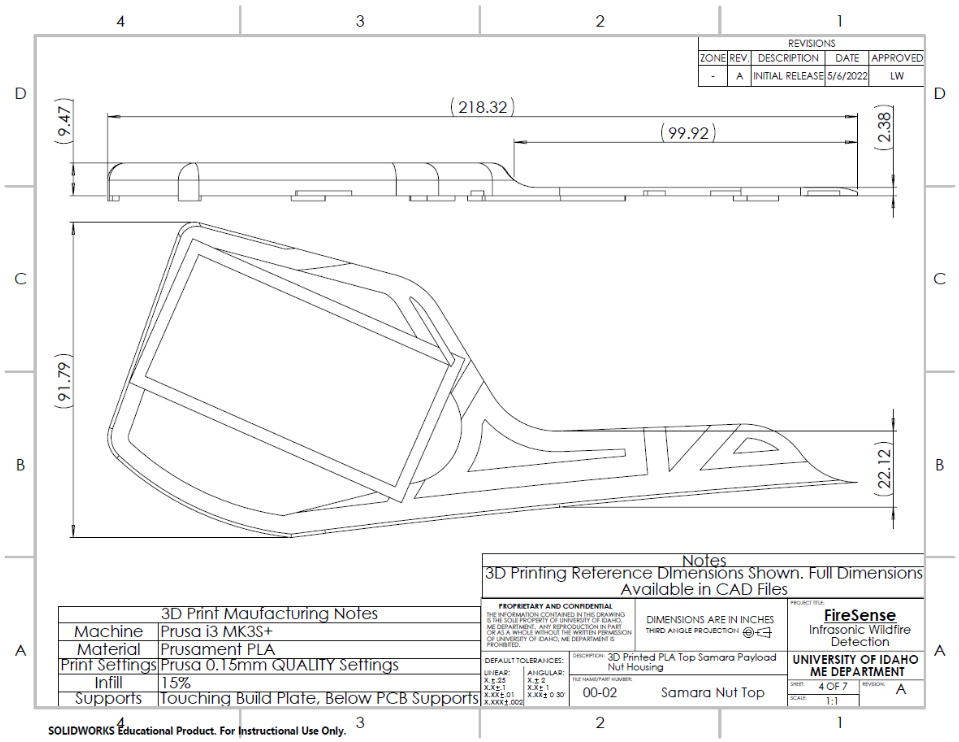


Figure 18: Technical Drawing Package Sheet 4, Samara Nut Top

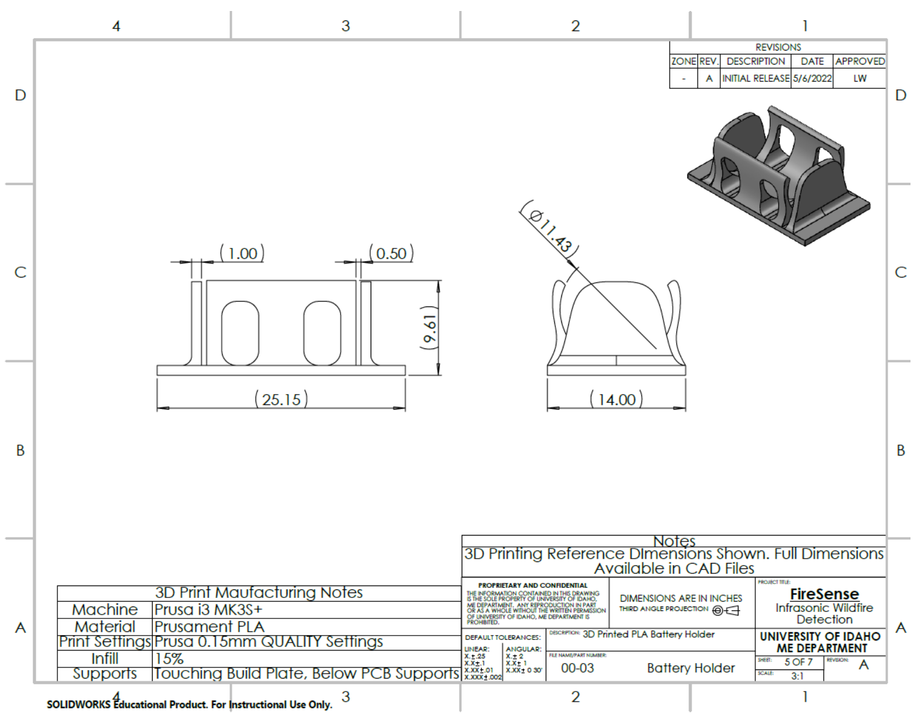


Figure 19: Technical Drawing Package Sheet 5, Battery Holder

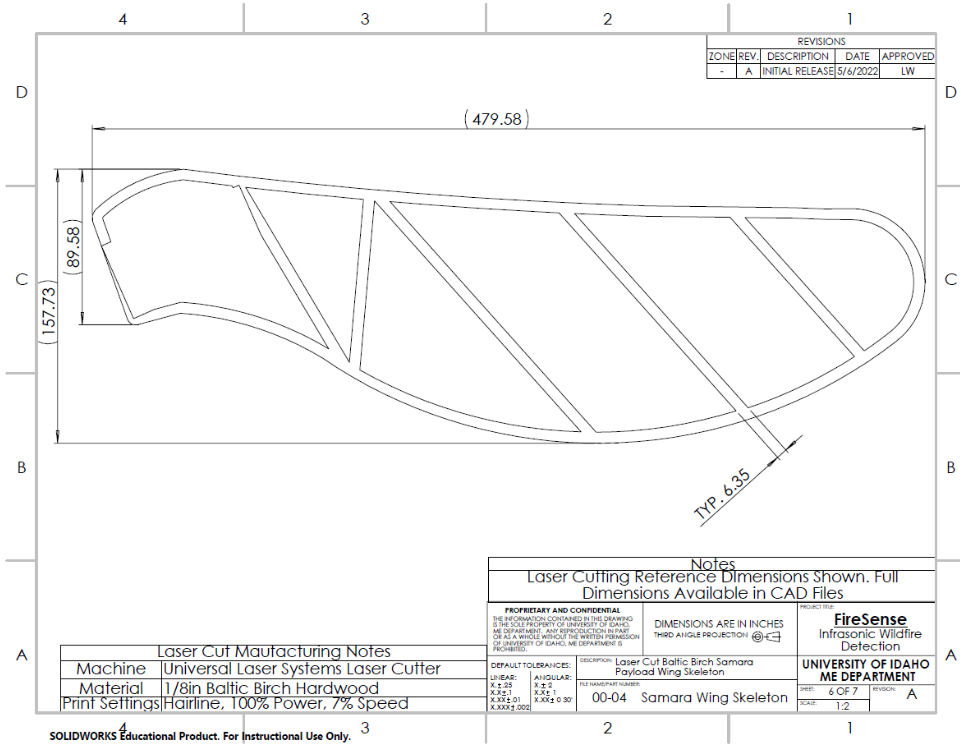


Figure 20: Technical Drawing Package Sheet 6, Samara Wing Skeleton

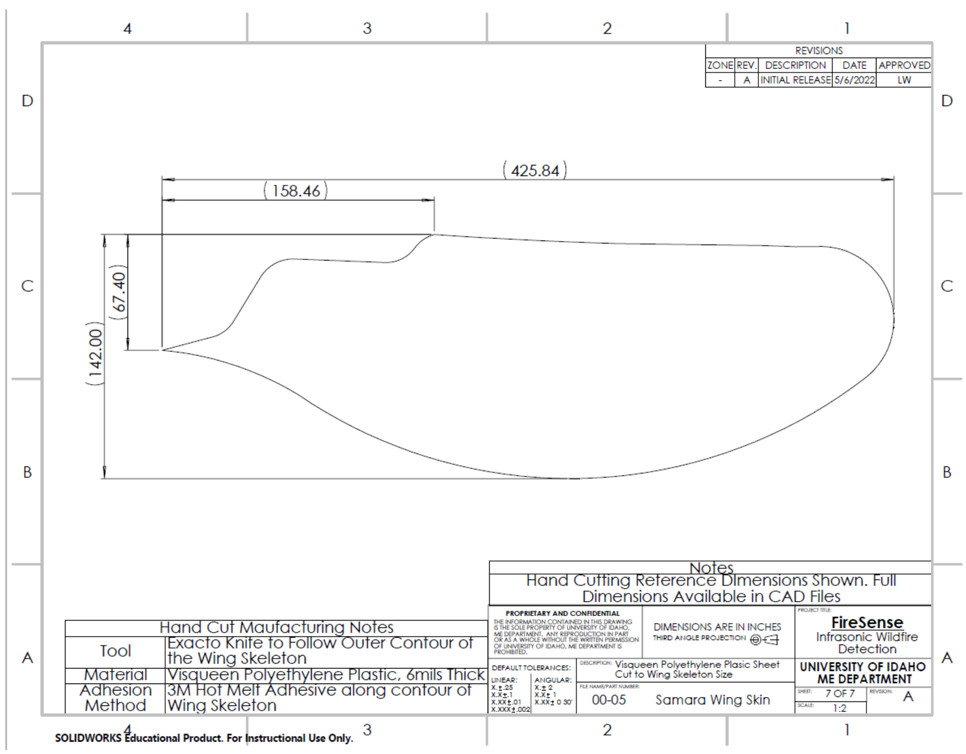
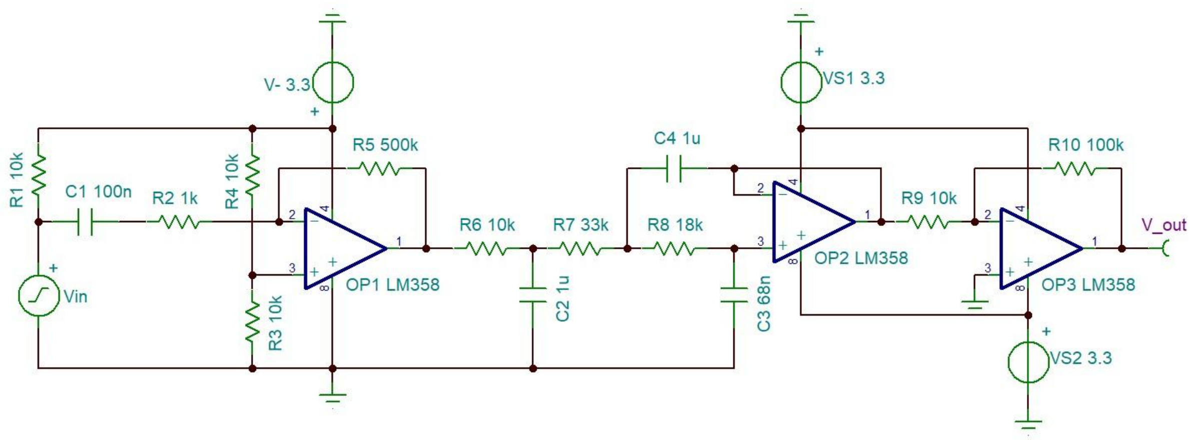
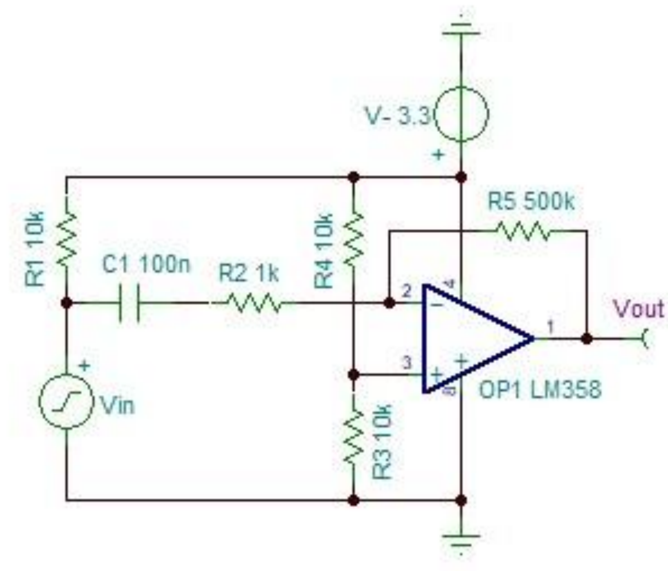


Figure 21: Technical Drawing Package Sheet 7, Samara Wing Skin

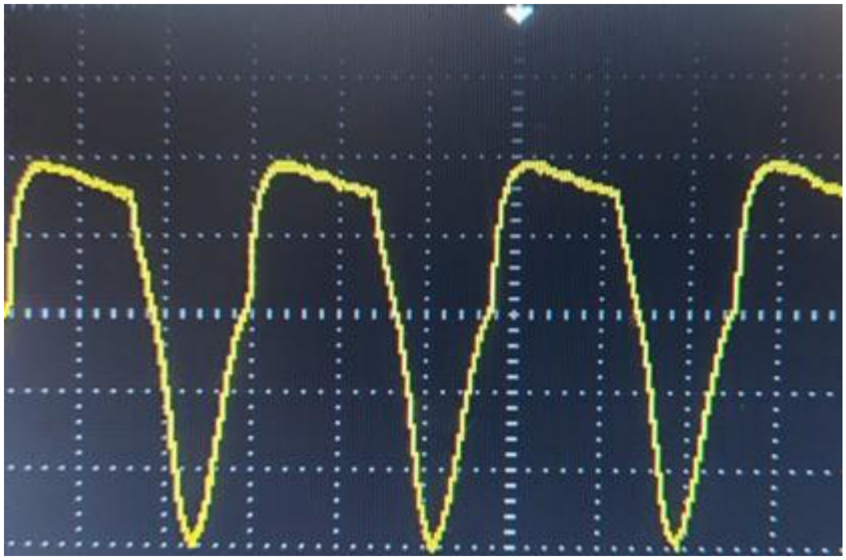
Large Tables and Figures



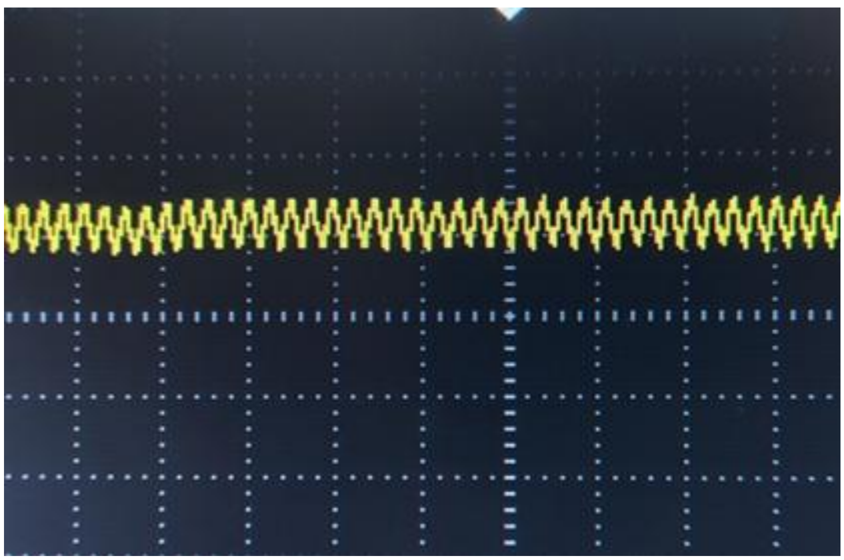
Full low-pass (Sallen-Key topology) filter circuit, modified from previous team's work



Pre-amplification circuit, microphone represented by source Vin



Microphone filter output, sinusoidal input at 10 Hz



Microphone filter output, sinusoidal input at 80 Hz

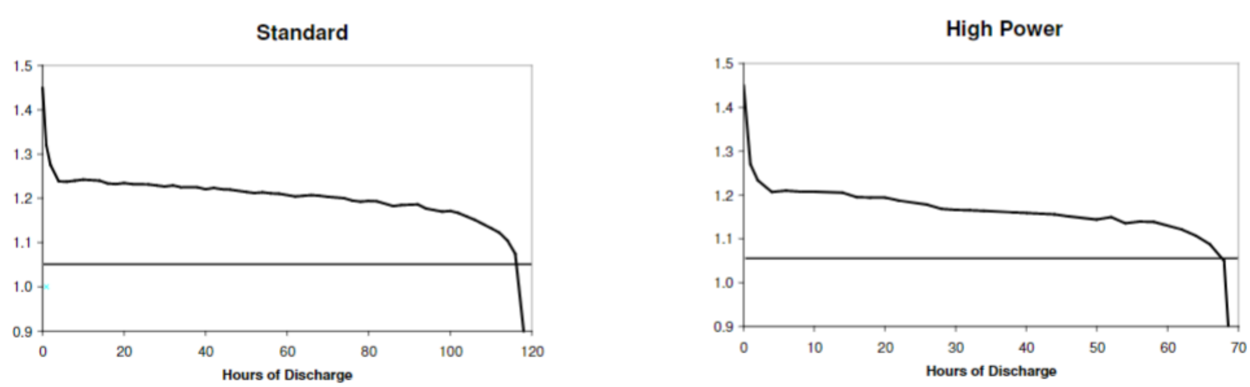


Figure : Typical Discharge Performance of Zi-Air Cell

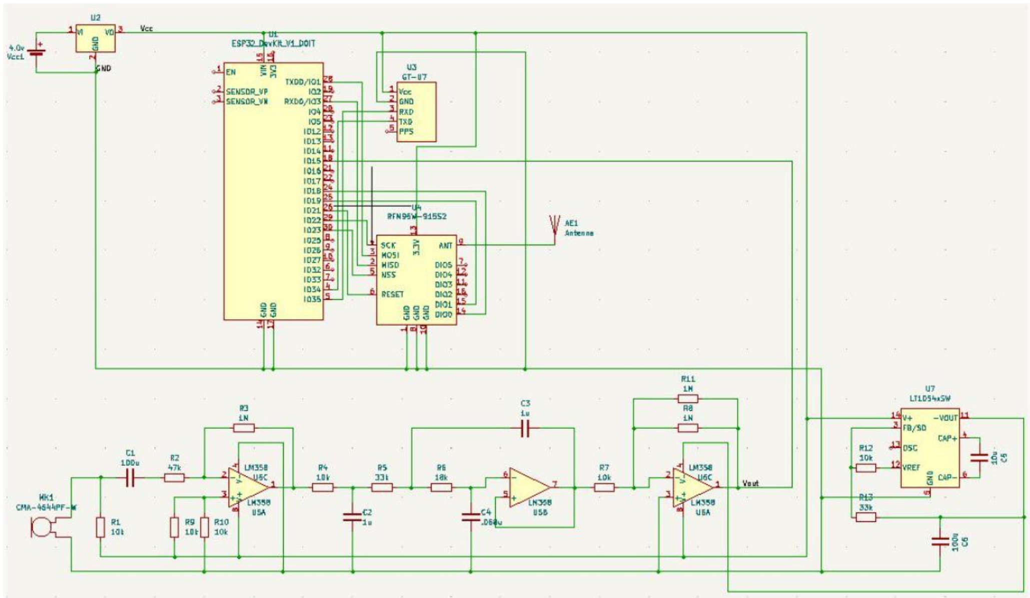


Figure 22:PCB Schematic

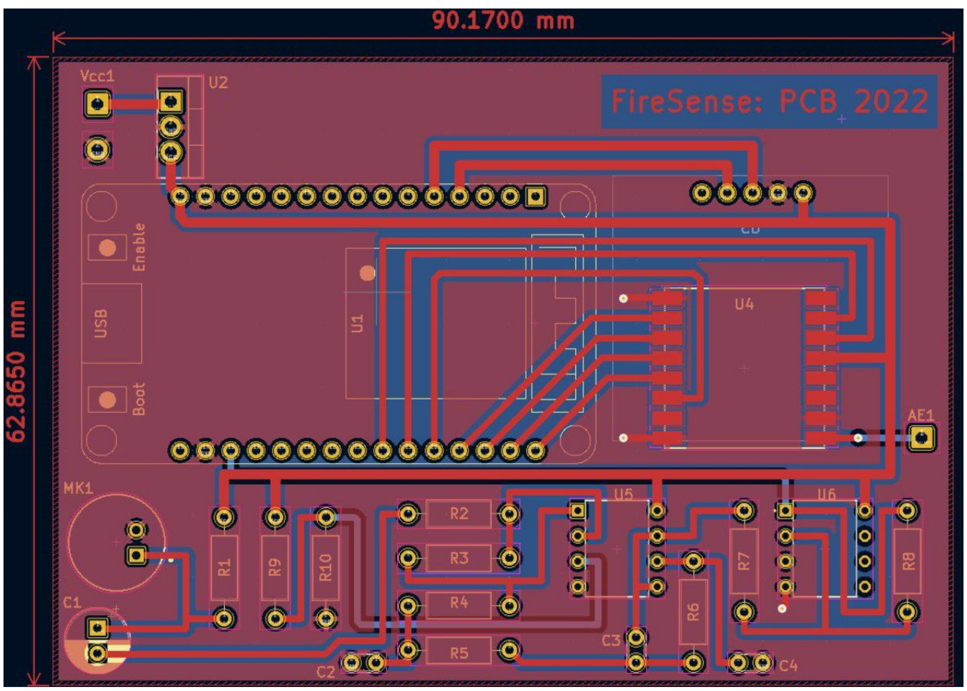


Figure 23: PCB_v1: THT Components

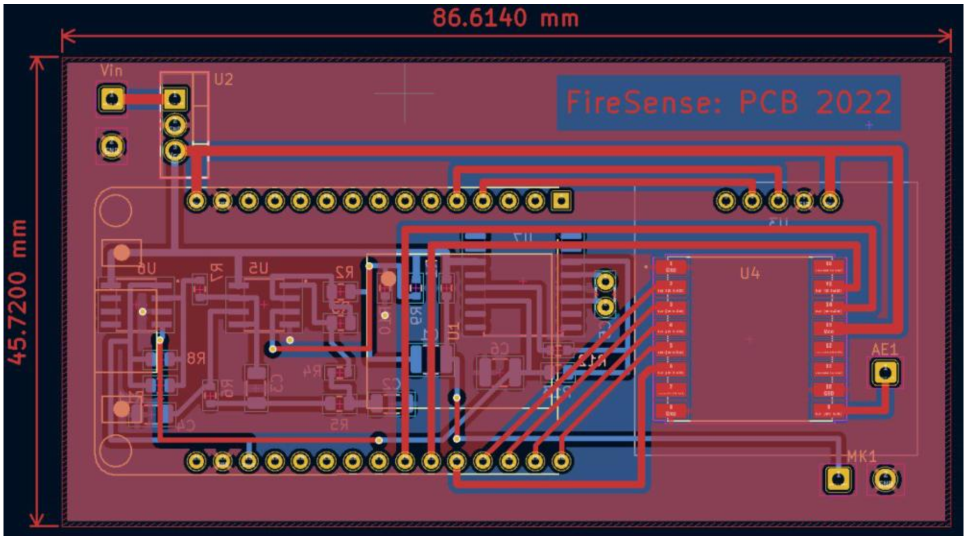


Figure 24: PCB_v2: SMT Components

Component	**# per PCB**	**Total Cost ($)**
Voltage Regulator (TC1262)	1	0.93
Dev Board (ESP32)	1	7.3
GPS (GT-U7)	1	9.5
Transceiver (RMF95W)	1	5.6
Microphone (CMA-4544PF)	1	0.66
Op-Amp (LM358)	2	0.4
Voltage Inverter (LT1054)	1	2.44
Zi-Air Battery (675ZM)	6	1.85
Cap (0.068uF)	1	0.36
Cap (1.0uF)	2	0.56
Cap (10.0uF)	1	0.43
Cap (100.0uF)	2	0.78
Res (10k)	6	0.56
Res (18k)	1	0.09
Res (33k)	2	0.16
Res (47k)	1	0.08
Res (1M)	3	0.24
PCB 2022:	31.94	
PCB 2021:	50	(Estimated Average)
Cost Reduction:	($50.00 - $31.94) / $50.00 = **36.12 % Cheaper**	

Figure 25: PCB Cost Breakdown

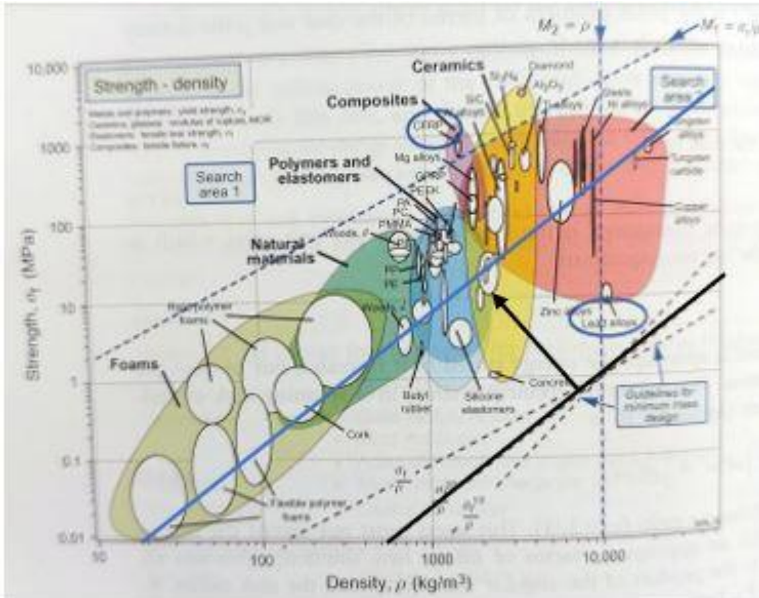


Figure 26: Materials Selection Table

Computer Programs

KiCad EDA – Schematic Capture & PCB Design Software (v6.0)
TINA-TI v9 (9.3.200.277 SF-TI)

Prusa Slicer 2.4.1

SOLIDWORKS 2021

Vendor Data Sheets

Active Electrical Components

ESP32
ESP32 Development Board
LM358
Transceiver
GT-U7
Batteries

Passive Electrical Components

Thin Film Resistors
KEMET Tantalum SMT Capacitors
Kyocera AVX Tantalum SMT Capacitors

Plusivo 24AWG Hook Up Wire Kit

Description Product Details

The Plusivo Hook up Assorted Wire Kit includes:

- Black AWG 24 Tinned Copper Silicone Wire (30 ft)
- Red AWG 24 Tinned Copper Silicone Wire (30 ft)
- Yellow AWG 24 Tinned Copper Silicone Wire (30 ft)
- Green AWG 24 Tinned Copper Silicone Wire (30 ft)
- Blue AWG 24 Tinned Copper Silicone Wire (30 ft)
- White AWG 24 Tinned Copper Silicone Wire (30 ft)
- Heatshrink Tubes
- Colored Wire Ties Mini Wire Stripper Tool

Tinned Copper Core

The benefits of having tinned copper wire include protection against corrosion, ease of soldering, and providing the same conductivity as bare copper.

Uniformly Coated with Silicone

The uniform insulation makes the wire easy to strip and cut. The Silicone insulation provides high flexibility, resistance to acids, oils, alkalies, moisture, and fungus, and offers good abrasion resistance.

Comes with these Additional Items

The kit includes a set of heat shrink tubes, a mini wire stripper tool, and colored wire ties, which may be used for other everyday projects.

Hook-Up Wire Kit

24 AWG Stranded Core

Stranded Core Hook-up Wires are more flexible than solid core wire of equal size, making them perfect for wiring circuits on frequently moving parts like robot arms.

Kit Includes:

- 6 x hook-up wire rolls (black, white, red, blue, green, yellow)
- 60 x wire ties / 10 per color (black, white, red, blue, green, yellow)
- 1 x heat shrink tube set (black, red, yellow)
- 1 x mini wire stripper

Plusivo Hook-Up Wires are assorted in colors for easy identification and color coding. The wires are contained in a box casing to keep your workspace organized. Items included are mini wire stripper, heat shrink tubes, and wire ties.

Conductor Size / Number	24 AWG / 40 pcs
Strand Diameter	0.08 mm
Insulation Thickness/Material	0.2 mm/Silicone
Conductor Diameter / Material	0.58 mm / Tinned Copper
Outer Diameter	1.6 mm

Conductor Resistance	91.6 Ω/km
Rated Voltage	600 V
Rated Temperature	200 degrees C
Packaging	6 different colored 29 Feet spools
Applications	Model airplanes, RC toys, Remote Control, Electronic, Battery Cable, drones, DIY, etc

Don't delay. Buy today.

[Clear Gorilla Glue]

APPLICATION TEMPERATURE – 32° to 100° F, best at room temperature

SERVICE TEMPERATURE – -20° to 180° F

OUTDOOR – Yes

MOISTURE RESISTANT – Water resistant – not recommended for continual water exposure

PAINTABLE – Yes – Can be painted with oil-based and spray. acrylic/latex and stains require sanding

SANDABLE – Yes

STAINABLE – Yes – Will require sanding

EXPANDS WHEN CURED – No

CURED COLOR – Clear

TECHNICAL STANDARDS – ANSI/HPVA Type II

STORAGE TIPS – Store in a cool, dry location. Store with access to light, if possible.

GAP FILLING – Minimal

Material Datasheets

PRUSA POLYMERS by JOSEF PRUSA

Version: 1.0
Last update: 20-09-2018

TECHNICAL DATA SHEET

Prusament PLA by Prusa Polymers

PLA is the most commonly used filament. It's biodegradable, easy to print, and very strong. The perfect choice for printing large objects thanks to its low thermal expansion (little to no warping) and for printing tiny parts because of its low melting temperature.

APPLICATIONS: Concept models, functional prototypes, low-wear toys, etc.

NOT SUITABLE FOR: Long term outdoor usage because of low temperature resistance (up to 60 °C).

POST-PROCESSING: Wet sanding. Without water you'll quickly start heating the plastic by friction, it will melt locally and make it hard to keep sanding.

IDENTIFICATION:

Trade name	Prusament PLA
Chemical name	Polylactic Acid
Usage	FDM 3D printing
Manufacturer	Prusa Polymers, Prague, Czech Republic

RECOMMENDED PRINT SETTINGS:

Nozzle Temperature [°C]	210 ± 10
Heatbed Temperature [°C]	40–60
Print Speed [mm/s]	up to 200

Figure 27: Technical Datasheet Prusament PLA Sheet 1

PRUSA POLYMERS by JOSEF PRUSA

TYPICAL MATERIAL PROPERTIES:

Physical Properties	Typical Value	Method
Peak Melt Temperature [°C]	145-160	ISO 11357
Glass Transition Temperature [°C]	55-60	ISO 11357
MFR [g/10min](1)	10.4	ISO 1133
MVR [cm3/10min](1)	9.4	ISO 1133
Specific Gravity [g/cm3]	1.24	ISO 1183
Moisture Absorption 24 hours [%](2)	0.3	Prusa Polymers
Moisture Absorption 7 days [%](2)	0.3	Prusa Polymers
Moisture Absorption 4 weeks [%](2)	0.3	Prusa Polymers
Heat Deflection Temperature (0,45 MPa) [°C]	55	ISO 75
Tensile Yield Strength Filament [MPa]	57.4 ± 0.4	ISO 527-1

MECHANICAL PROPERTIES OF PRINTED TESTING SPECIMENS(3):

Property / print direction	Horizontal	Vertical X, Y-Axis	Vertical Z-Axis	Method
Tensile Modulus [GPa]	2,2 ± 0,1	2,4 ± 0,1	2,3 ± 0,1	ISO 527-1
Tensile Yield Strength [MPa]	50,8 ± 2,4	59,3 ± 1,9	37,6 ± 4,0	ISO 527-1
Elongation at Yield Point [%]	2,9 ± 0,3	3,2 ± 0,1	1,9 ± 0,3	ISO 527-1
Impact Strength Charpy(4) [kJ/m2]	12,7 ± 0,7	13,7 ± 0,7	5,0 ± 1,4	ISO 179-1

(1) 2,16 kg; 210 °C |
(2) 28 °C; humidity 37 %
(3) Original Prusa i3 MK3 3D printer was used to print testing specimens. Slic3r Prusa Edition 1.40.0 was used to create G-codes with following settings: Prusa PLA Filament; Print settings 0,20mm FAST (layers 0,2mm); solid layers Top: 0 Bottom: 0; Infill 100% Rectilinear, infill print speed 200mm/s; extruder temperature 215°C all layers; bed temperature 60°C all layers; other parameters set to default | (4) Charpy Unnotched, edgewise direction of blow according to ISO 179-1

Disclaimer

The results presented in this data sheet are just for your information and comparison. Values are significantly dependent on print settings, operators experiences and surrounding conditions. Everyone have to consider suitability and possible consequences of printed parts usage. Prusa Polymers can not carry any responsibility for injures or any loss caused by using of Prusa Polymers material.

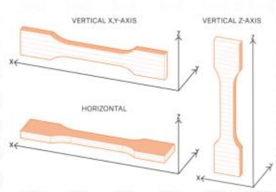


Figure 28: Technical Datasheet Prusament PLA Sheet 2

TECHNICAL DATA SHEET

Super Glue Ultra Liquid Control®

Description: Loctite Super Glue Ultra Liquid Control is a user-friendly formulation designed for home use that forms strong rapid bonds between a wide range of common materials and offers improved performance in bonding materials exposed to moisture and humidity. The product provides rapid bonding to porous materials such as wood, paper, leather and fabric. Loctite Super Glue Ultra Liquid Control comes in a patented side-squeeze design for maximum control. It dries clear and sets without clamping.

Available As:

Item #	Size	Package
1647358 1661517	4 g	Carded Bottle

Features & Benefits:

- Precise Application
- Thin & Fast
- Dries Transparent
- Water Resistant

Recommended For: Use for repairing figurines, costume jewelry, cameras, toys, metal car parts, wiper blades, rubber seals and O-rings. Bonds leather, cork, paper, cardboard, wood, chipboard, fabric, metal, ceramic, rubber and hard plastics such as acrylic, polycarbonate, polystyrene and PVC.

For Best Results:

- Do not use on polyethylene (PE), polypropylene (PP), polytetrafluoroethylene (PTFE), silicone or foam rubber, polystyrene foams, glass, very soft leathers or pure bone china
- Do not use in dishwasher, oven or microwave
- Not suitable for bonding assemblies which will hold hot liquids
- Do not use on glazed surfaces
- Not suitable for exterior applications
- Not suitable for repairs needing high flexibility or for gap-filling applications

Loctite® Super Glue
Ultra Liquid Control®
Page 1 of 3

Figure 29: Technical Datasheet Loctite Super Glue Sheet 1

TECHNICAL DATA SHEET

Typical Uncured Physical Properties:	Color:	Clear and Colorless	
	Appearance:	Liquid	
	Adhesive Base:	Ethyl cyanoacrylate	
	Odor:	Sharp, irritating (use in a well-ventilated area)	
	Specific Gravity:	1.05	
	Flash Point:	176°F (80°C) to 200°F (93°C)	
	VOC Content:	< 2 % by weight	CARB
		< 20 g/l	SCAQMD rule 1168
	Shelf Life:	From date of manufacture (unopened) : 30 months 18 months	 Stored at 36-46°F Stored at 68°F
	Lot Code Explanation:	**YDDD**XX	
	Printed on bottom of bottle	**Y=** Last digit of year of manufacture **DDD=** Day of manufacture based on 365 days in a year XX = Disregard	
		Example: 5061 = 61st day of 2015 = March 2, 2015	
Typical Application Properties:	Application Temperature:	Apply above 50°F (10°C)	
	Fixture Time:	10 to 30 seconds*	
	Handling Time:	Leave undisturbed for at least 5 minutes.	
		For best results, allow full bond strength to develop overnight before handling.	
	Cure Time:	12 to 24 hours*	
		*Times are dependent on temperature, humidity, porosity of surface bonded and amount of adhesive used	
Typical Cured Performance Properties:	Color:	Clear and Colorless	
	Cured Form:	Non-flammable, brittle solid	
	Service Temperature:	Up to 180°F (82°C)	
	Moisture Resistant:	Yes. Conforms to EN204 D3 Water Resistance Standard	
	Tensile Shear Strength:	Varies from 1450-2900 psi (10-20 N/mm²)	ISO 4587 12-24 hours cure, depending on the substrate
	Aluminum:	2248 psi (15.5 N/mm²)	

Directions:

Tools Typically Required:
Tissue paper

Safety Precautions:
Use in a well-ventilated area. Protect work area. Wash hands after use.

Preparation:
Surfaces to be bonded must be close fitting, clean, dry and free from oil, wax and paint. Protect work area. For best results, lightly roughen smooth surfaces. Pre-fit parts to be joined.

Application:
In a clockwise direction, screw the closure cap tightly in to the base until the clicking sound stops. Unscrew the cap in a counter clockwise direction. Squeeze red side grips for precision dispensing. Apply the adhesive sparingly to one surface only using approximately one drop per square inch of surface. Press surfaces together immediately. Hold in place for 10 to 30 seconds until bond sets. Do not reposition parts. Clean tip with tissue and replace the cap screwing it down tightly in a clockwise direction. For increased strength, leave bond undisturbed for at least ten minutes. Full cure in 24 hours. Note: Cure time is dependent upon temperature, humidity, porosity of surfaces and amount of adhesive applied.

Loctite® Super Glue
Ultra Liquid Control®
Page 2 of 3

Figure 30: Technical Datasheet Loctite Super Glue Sheet 2

LOCTITE TECHNICAL DATA SHEET

Clean-up:
After cleaning, wet any tissue used for wiping off glue with water and dispose of. When cleaning up larger quantities of uncured adhesive, apply water and allow to cure and then scrape up. Note this may result in damage to the surfaces. Cured adhesive may be cut away with caution using a sharp blade, removed with acetone or with boiling water. Note: Acetone may damage some plastics and is also highly flammable. Test before use and follow manufacturer's instructions.

Storage & Disposal: Not damaged by freezing in the unopened container. Optimal shelf life is achieved when unopened container is stored from 36°F to 46°F (2°C to 8°C). After opening, it is not recommended that the product be stored cold or frozen. Once opened, the product is best stored tightly sealed in a dry location away from heat sources or sun exposure. Humidity and high temperatures may decrease shelf life. Use an approved hazardous waste facility for disposal.

Label Precautions: **WARNING:** Contains Cyanoacrylate. Can cause severe eye injury. Bonds skin instantly. May cause allergic skin reaction. Skin contact may cause burns. Use in a well ventilated area. Avoid contact with skin and eyes. FIRST AID: In case of eye contact, flush with water for 15 minutes; call a physician. For skin contact, flush with water. For ingestion, do not induce vomiting; call a physician. If spilled on clothing, flush with large quantities of water. **KEEP OUT OF REACH OF CHILDREN.**

Refer to Safety Data Sheet (SDS) for further information.

Disclaimer: The information and recommendations contained herein are based on our research and are believed to be accurate, but no warranty, express or implied, is made or should be inferred. Purchasers should test the products to determine acceptable quality and suitability for their own intended use. Nothing contained herein shall be construed to imply the nonexistence of any relevant patents or to constitute a permission, inducement or recommendation to practice any invention covered by any patent, without authority from the owner of the patent.

Trusted Performance. Proven Results.
For over 50 years, Loctite Brand adhesives and sealants have taken on the toughest jobs. Used in race cars, airplanes, and even in the space-shuttle, Loctite provides solutions for the most demanding industrial, professional and consumer applications. Loctite gives you not the specialization, power and performance to not only get your job done, but to get it done right.

1-800-624-7767 – Mon-Fri - 9:00a – 4:00p ET
www.loctiteproducts.com

Loctite Brand is part of the Henkel family of brands. Founded in 1876, Henkel is a global leader in the consumer and industrial businesses. Henkel operates worldwide with leading brands and technologies in three business areas: Laundry & Home Care, Beauty Care and Adhesive Technologies.

Henkel Corporation - Professional & Consumer Adhesives Headquarters - Rocky Hill, CT 06067
www.henkelna.com

Revision Date: 08/30/2016 Supercedes: 07/03/2014 Ref. #: 158590 Bulk #: 924084

Loctite® Super Glue
Ultra Liquid Control®
Page 3 of 3

Figure 31: Technical Datasheet Loctite Super Glue Sheet 1

3M
Hot Melt Adhesive
3747 • 3779 • 3789 • 3797

Technical Data **July, 2016**

Product Description 3M™ Hot Melt Adhesives are heat applied, 100% solids adhesives. 3M™ Hot Melt 3747, 3779, 3789 and 3797 are thermoplastic adhesives to bond to wide variety of substrates such as wood, plastic, vinyl, metal and glass.

3M™ Hot Melt Adhesive 3747 General purpose adhesive for bonding dissimilar substrates such as wood to plastic, fabric to metal.

3M™ Hot Melt Adhesive 3779 High strength bonding with excellent environmental stability including very high heat resistance. Fast set time.

3M™ Hot Melt Adhesive 3789 High performance for plastic with good fuel, oil and plasticizer resistance. Long open time.

3M™ Hot Melt Adhesive 3797 Low viscosity for fast flow rates, good high temperature resistance, and fast set. Good for electrical potting.

Features

- 100% solids, no VOCs
- Easy to use
- Long open times allow for easy use on large assemblies and large surfaces
- Adhesive sets and obtains strength in seconds
- Creates high performance bonds
- Ideal for woodworking and general industrial applications.

Typical Physical Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

	3M™ Hot Melt Adhesive			
	3747	**3779**	**3789**	**3797**
Color (solid)	Tan	Amber	Brown	Off-White
Density (g/cm^3)	0.97	0.99	0.95	0.92
Flashpoint (°F)[1]	509	550	>392	570

(1) Determined by Cleveland Open Cup ASTM D 92-72.

Directions for Use

1. Surface Preparation: Surfaces must be clean, dry and dust free. Wipe with a solvent such as isopropyl alcohol for plastic, metal and glass substrates to remove oil and dirt.* ***Note:** When using solvents, extinguish all ignition sources, including pilot lights, and follow the manufacturer's precautions and directions for use.

2. Application: 3M™ Hot Melt Adhesives are designed for application with a 3M™ Hot Melt Applicators. Read and follow the precautions and directions for use in the user's manual before operating the applicator. 3M™ Hot Melt Adhesives are applied at 350-385°F. Adhesives yield approximately 430 linear feet per pound of adhesive when extruded as a 1/8" diameter semi-circular bead. Extruded bead sizes can be customized using 3M™ applicator tips.

Figure 32: Technical Datasheet 3m Hot Melt Adhesive Sheet 1

3M™ Hot Melt Adhesive
3747 • 3779 • 3789 • 3797

Directions for Use (continued)

3. Coverage: 3M™ Hot Melt Adhesives yield approximately 430 linear feet per pound of adhesive when extruded as a 1/8" diameter semi-circular bead.

4. Set up time: After the bond is made, 3M™ Hot Melt Adhesives immediately build strength and no clamping is necessary. Set will occur faster on cold or metallic substrates.

Typical Application Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

	3M™ Hot Melt Adhesive			
	3747	**3779**	**3789**	**3797**
Application Temperature[1]	350-385°F/ 177-196°C	350-385°F/ 177-196°C	350-385°F/ 177-196°C	350-385°F/ 177-196°C
Viscosity (CPS)[2]	4,100 @ 375°F	7,000 @ 375°F	5,200 @ 375°F	2,650 @ 375°F
Open Time (seconds)[3]	45	25	50	30
Delivery Time (seconds)[4]	45	75	70	55
Available sizes/forms	5/8"x8" Q 5/8"x2" TC 1"x3" PG 1/2"x12" AE	5/8"x8" Q 5/8"x2" TC 1"x3" PG 1/8" Bulk	5/8"x8" Q 1"x3" PG 1/8" Bulk	5/8"x2" TC 1"x3" PG

(1) Recommended application temperature range. Temperature can be adjusted to regulate desired viscosity, delivery rate and pot life.
(2) Brookfield Thermocel Viscometer in Centipoise using a #27 Spindle @ 10 RPM.
(3) Open time is the maximum time between the application of the adhesive and when the parts must be joined together. Data based on 1/8" semicircular bead on non-metallic substrates at 75°F. Higher environmental temperatures and/or larger beads will lengthen open times.
(4) Extrusion time for one 1"x3" PG cartridge.

Typical Performance Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

	3M™ Hot Melt Adhesive			
	3747	**3779**	**3789**	**3797**
Heat Resistance[1]	145°F/ 63°C	300°F/ 149°C	220°F/ 104°C	170°F/ 77°C
Ball & Ring Melt Point[2]	220°F/ 104°C	325°F/ 163°C	270°F/ 132°C	304°F/ 151°C
Shear Strength[3]	430 psi	700 psi	570 psi	350 psi
Peel Strength[4]	20 piw	18 piw	16 piw	10 piw
UL94 Listing	n/a	V0	V2	V2
FDA Indirect Food Contact[5]	21 CFR 175.105	21 CFR 175.105	21 CFR 175.105	21 CFR 175.105

(1) Highest temperature that the adhesive will support a 2 psi dead load
(2) ASTM E28-67
(3) Overlap shear measured on Douglas Fir to Douglas Fir
(4) Measured in pounds per inch width (piw). Flexible canvas bonded to Douglas Fir
(5) Permitted for indirect food contact subject to the limitations in applicable CFR section(s).

Figure 33: Technical Datasheet 3m Hot Melt Adhesive Sheet 2

3M™ Hot Melt Adhesive
3747 • 3779 • 3789 • 3797

Storage

Store product below 120°F (49°C).

Shelf Life

When stored at the recommended conditions, this product has a shelf life of 2 years after 3M ships the product to a customer or distributor.

Precautionary Information

Refer to Product Label and Material Safety Data Sheet for health and safety information before using this product. For additional health and safety infomation, call 1-800-364-3577 or (651) 737-6501

Product Use

All statements, technical information and recommendations contained in this document are based upon tests or experience that 3M believes are reliable. However, many factors beyond 3M's control can affect the use and performance of a 3M product in a particular application, including the conditions under which the product is used and the time and environmental conditions in which the product is expected to perform. Since these factors are uniquely within the user's knowledge and control, it is essential that the user evaluate the 3M product to determine whether it is fit for a particular purpose and suitable for the user's method of application.

Warranty and Limited Remedy

Unless stated otherwise in 3M's product literature, packaging inserts or product packaging for individual products, 3M warrants that each 3M product meets the applicable specifications at the time 3M ships the product. Individual products may have additional or different warranties as stated on product literature, package inserts or product packages. 3M MAKES NO OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR ANY IMPLIED WARRANTY ARISING OUT OF A COURSE OF DEALING, CUSTOM OR USAGE OF TRADE. User is responsible for determining whether the 3M product is fit for a particular purpose and suitable for user's application. If the 3M product is defective within the warranty period, your exclusive remedy and 3M's and seller's sole obligation will be, at 3M's option, to replace the product or refund the purchase price.

Limitation of Liability

Except where prohibited by law, 3M and seller will not be liable for any loss or damage arising from the 3M product, whether direct, indirect, special, incidental or consequential, regardless of the legal theory asserted, including warranty, contract, negligence or strict liability.

ISO 9001:2000

This Industrial Adhesives and Tapes Division product was manufactured under a 3M quality system registered to ISO 9001: 2000 standards.

3M

Industrial Adhesives and Tapes Division
3M Center, Building 225-3S-06
St. Paul, MN 55144-1000
800-362-3550 • 877-369-2923 (Fax)
www.3M.com/Adhesives

Figure 34: Technical Datasheet 3m Hot Melt Adhesive Sheet 3

Project Schedule

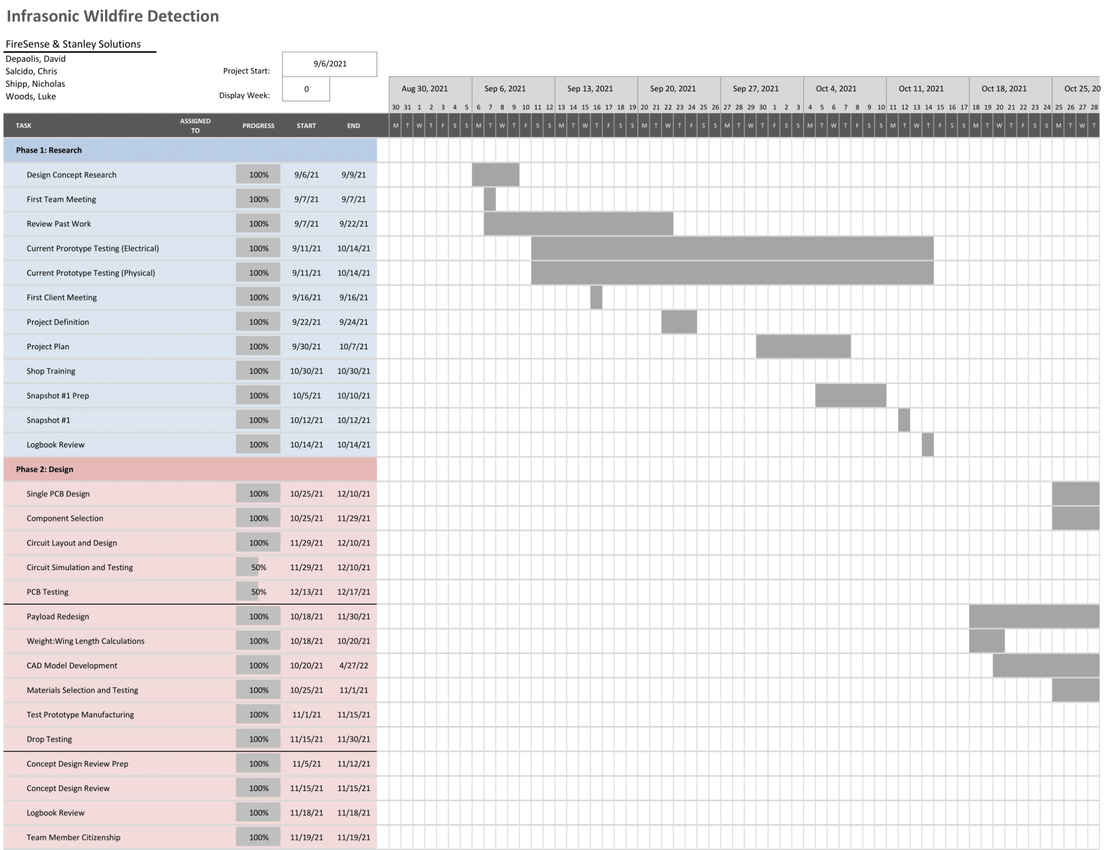


Figure 35: Team FireSense Gantt Chart, First Half of Tasks Sheet 1

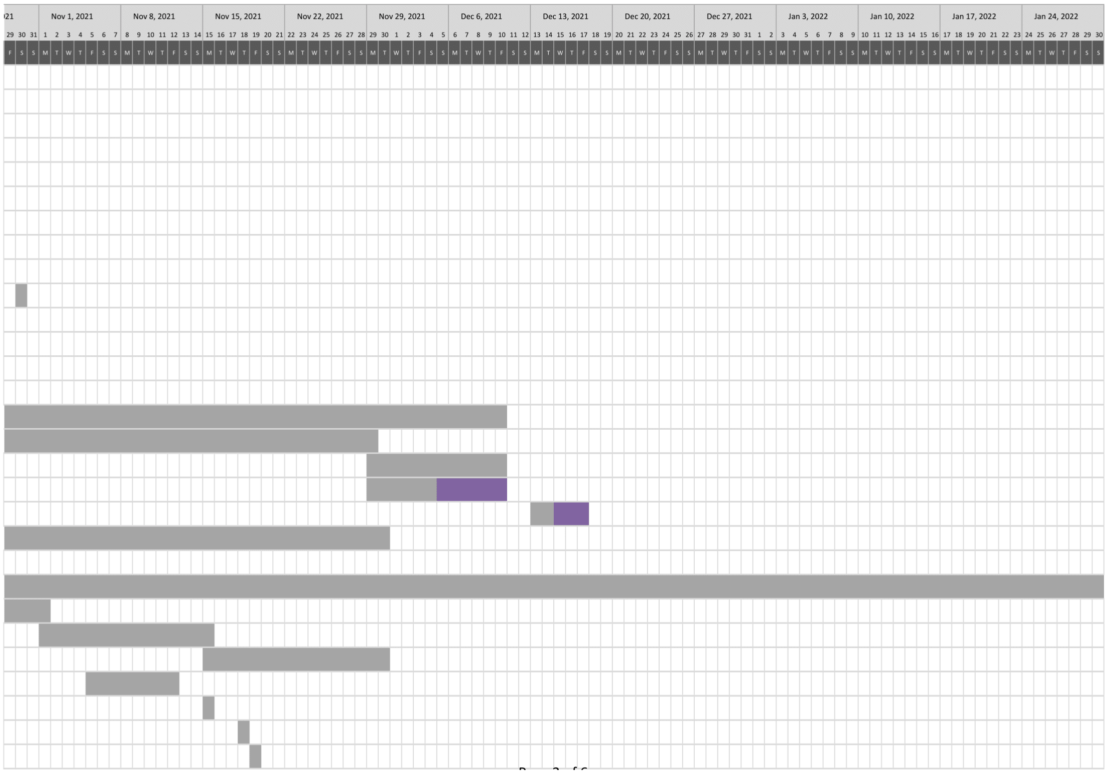


Figure 36: Team FireSense Gantt Chart, First Half of Tasks Sheet 2

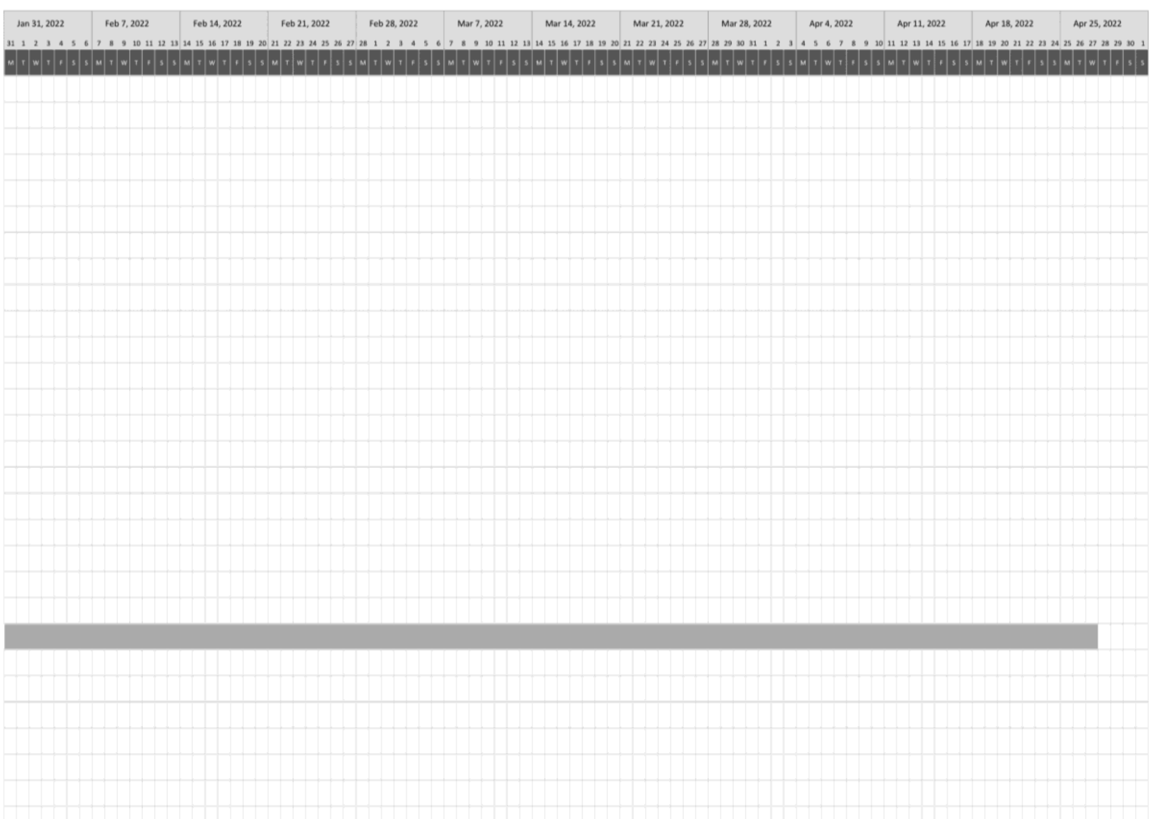
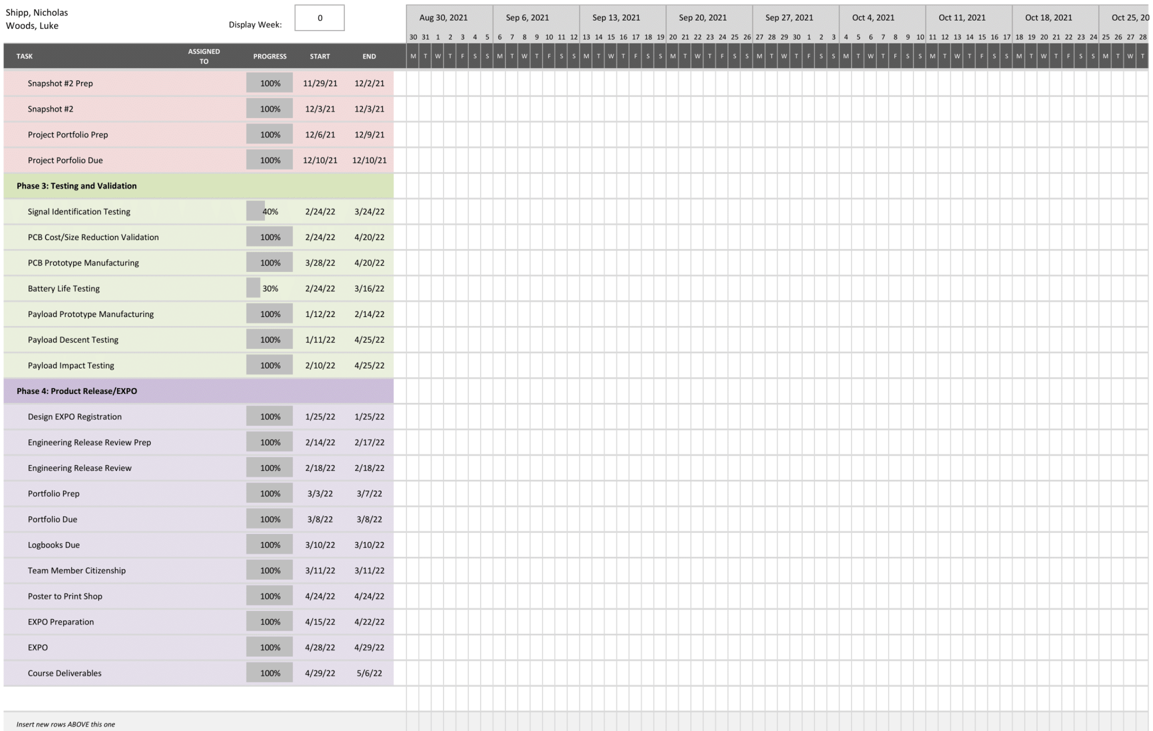


Figure 37: Team FireSense Gantt Chart, First Half of Tasks Sheet 3



Shipp, Nicholas
Woods, Luke

Display Week: 0

TASK	ASSIGNED TO	PROGRESS	START	END
Snapshot #2 Prep		100%	11/29/21	12/2/21
Snapshot #2		100%	12/3/21	12/3/21
Project Portfolio Prep		100%	12/6/21	12/9/21
Project Porfolio Due		100%	12/10/21	12/10/21
Phase 3: Testing and Validation				
Signal Identification Testing		40%	2/24/22	3/24/22
PCB Cost/Size Reduction Validation		100%	2/24/22	4/20/22
PCB Prototype Manufacturing		100%	3/28/22	4/20/22
Battery Life Testing		30%	2/24/22	3/16/22
Payload Prototype Manufacturing		100%	1/12/22	2/14/22
Payload Descent Testing		100%	1/11/22	4/25/22
Payload Impact Testing		100%	2/10/22	4/25/22
Phase 4: Product Release/EXPO				
Design EXPO Registration		100%	1/25/22	1/25/22
Engineering Release Review Prep		100%	2/14/22	2/17/22
Engineering Release Review		100%	2/18/22	2/18/22
Portfolio Prep		100%	3/3/22	3/7/22
Portfolio Due		100%	3/8/22	3/8/22
Logbooks Due		100%	3/10/22	3/10/22
Team Member Citizenship		100%	3/11/22	3/11/22
Poster to Print Shop		100%	4/24/22	4/24/22
EXPO Preparation		100%	4/15/22	4/22/22
EXPO		100%	4/28/22	4/29/22
Course Deliverables		100%	4/29/22	5/6/22

Insert new rows ABOVE this one

Figure 38: Team FireSense Gantt Chart, Second Half of Tasks Sheet 1

Figure 39: Team FireSense Gantt Chart, Second Half of Tasks Sheet 2

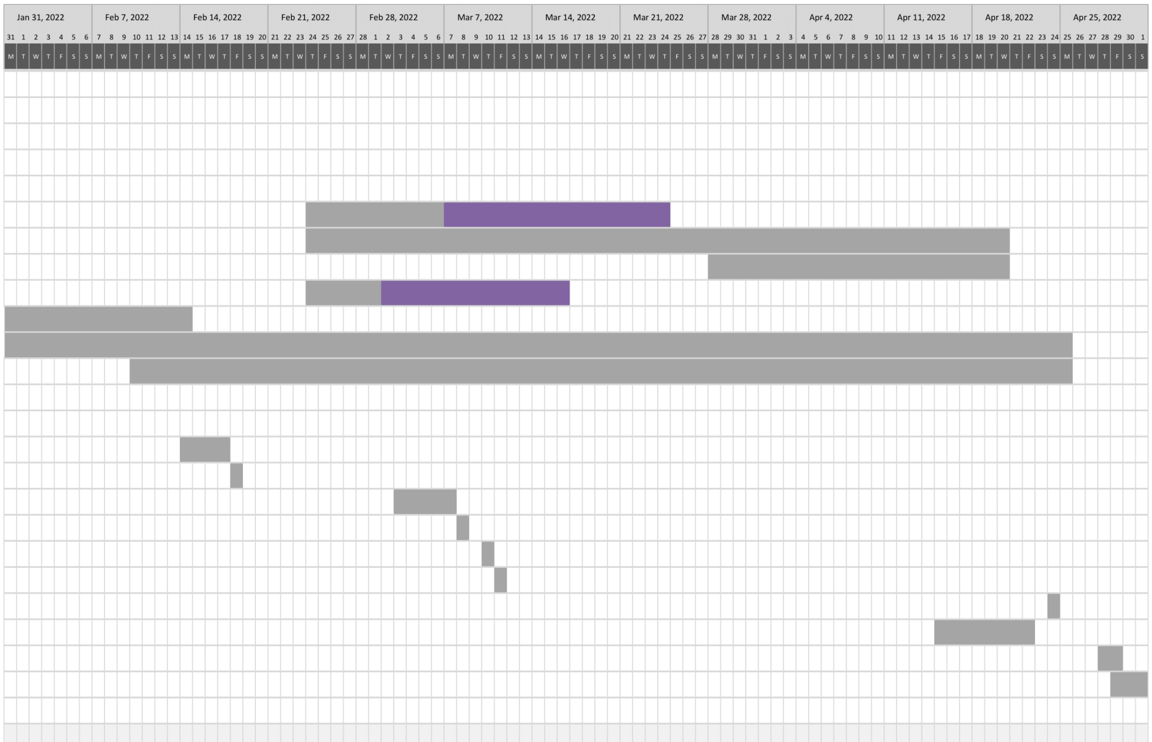


Figure 40: Team FireSense Gantt Chart, Second Half of Tasks Sheet 3

DFMEA Worksheet

System Infrasonic Wildfire Detection Device
Subsystem Electronics
Component All Subcomponents
Design Lead Nicholas Shipp
Core Team David DePaolis, Nicholas Shipp

Potential Failure Mode and Effects Analysis (Design FMEA)
Key Date 5/6/2022

FMEA Number
Prepared By Luke Woods
FMEA Date 5/6/2022
Revision Date
Page 1 of 1

Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	New Sev	New Occ	New Det	New RPN
Low-pass Filter	Attenuate input signals with frequencies above ~20 Hz	Component package corrosion	Failure to filter microphone input	6	Exposure to environmental humidity	6		3	108	Components with thermal tolerance and sealing						
Printed Circuit Board	Condense interconnections between devices in payload	Dust deposition, waterlogging, and other environmentals on tracks	Short circuits, passive component damage	5	Passive environmental effects	5		4	100	Sealing for payload capsule and a solder mask						
GPS Unit	Provide location data for the mesh network establishment	Maximum digital I/O current exceeded	Damaged pin I/O disables node in network	3	Environmentals shorting traces	5		6	90	Sealing for payload capsule and a solder mask						
Printed Circuit Board	Condense interconnections between devices in payload	Scratches, environemntal and/or flux corrosion on traces	Open circuits, power loss, false readings	6	Handling by operator or manufacturer, exposure	5		3	90	Implement a solder mask, change copper weight						
Low-pass Filter	Attenuate input signals with frequencies above ~20 Hz	Solder joint failure	Poor electrical connection or open circuits	5	Thermal stresses, manufacturing defects, or	3		4	60	Implement sealing and overspec solder						
Radio Transciever	Provide communications capabilities (LoRa modem) for nodes in the mesh network	Electrical damage in package	Malfunctioning node and mesh network break	3	ESD from handling	3		6	54	Professional manufacturing, protection on board for future bare-chip designs						
Microphone	Provide means to collect data from environment	Diaphragm, electret material and packaging thermal degredation	Reduced sensitivity and range	3	Exceptionally warm temps in specific environments with direct sunlight	2		7	42	Include warning for operator						
Microphone	Provide means to collect data from environment	Degraded solder joints	Reduction or complete loss of input signal	5	Cyclical thermal stresses from environment	4		2	40	Stress test prototype, Redesign PCB to permit mic replacement						
Voltage Regulator	Control the input battery voltage for the power rails on the PCB	Excess torque / mechanical damage in through-holes	Copper foil damaged / pulled away from board	6	Handling by operator or payload delivery	3		2	36	Solder mask and placement on board with clearance						

Figure 41: DFMEA Analysis of IWD Electronics Sheet 1

Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	New Sev	New Occ	New Det	New RPN
GPS Unit	Provide location data for the mesh network establishment	Maximum input voltage (3.6 V) exceeded	Inconsistent location data for intitialization	2	Failure of voltage regulator	2		2	**8**							
Radio Transciever	Provide communications capabilities (LoRa modem) for nodes in the mesh network	Insufficient range for message transmission	Isolated nodes are not included in the mesh network	5	Poor placement of payload during deployment	1		1	**5**	Test node density vs network reliability						

Figure 42: DFMEA Analysis of IWD Electronics Sheet 2

System Infrasonic Wildfire Detection Device
Subsystem Samara Payload
Component All Subcomponents
Design Lead Luke Woods
Core Team Chris Salcido, Luke Woods

Potential
Failure Mode and Effects Analysis
(Design FMEA)
Key Date 5/6/2022

FMEA Number
Prepared By Luke Woods
FMEA Date 5/6/2022
Revision Date
Page 1 of 1

Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	New Sev	New Occ	New Det	New RPN
Samara Body	House the PCB Payload and contribute to center of mass placement conducive to rotation.	Unfavorable Weight Distribution.	Rotation during flight may not be acheived and fall velocity could exceed safe parameters.	6	Misplaced components in assembly, excess material located on nut or wong.	8	Design reliance on lower-scaled model testing. Visual inspection of parts location before and after	4	**192**	Continue selecting Body Designs that succeed in testing to reproduce desired flight						
Samara Body	House the PCB Payload and contribute to center of mass placement conducive to rotation.	Incomplete sealing of payload body	Exposure to weather elements and debris	4	Assembly/Manufacturing Fit fit failure, improper application of sealant	3	Interference fits, sealing applied along all outer edge seals	7	**84**	paper in closed payload to test sealant. Seal around wing skeleton to prevent						
Samara Body	House the PCB Payload and contribute to center of mass placement conducive to rotation.	Fracture during impact.	Distruption of PCB function by disconnection of components, or exposure to weather elements and debris.	7	High Impact Force	4	Impact analysis testing, visual inspection of parts.	2	**56**	Drop testing experiments with varied thicknesses to determine minimum thickness. Cushion the						
Wing Skeleton	Provide the wing shape, structural support for the wing skin, and contribute to center of mass placement conducive to rotation.	Wing shape lacks lift production.	Wing may fall faster than safe parameters for the samara body.	6	Improper alighnment of wing during manufacturign/assembly, defective matieral/manufacturing process	3	Visual inspection, design fit with low tolerance	3	**54**	Create an inspection procedure for manufactured wings to asses useability						

Figure 43: DFMEA Analysis of IWD Samara Payload Body Sheet 1

Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
												Actions Taken	New Sev	New Oc	New Det	New RP
Wing Skin	Produce lift during flight by lining the wing skeleton.	Skin imporperly attached to Wing	Wing may fall faster than safe parameters for the samara body.	6	Adhesive imropery bonds, insufficient adhesive along skeleton,	4	Visual inspection, press test on wing skin sections	2	**48**	Test bonding agents that don't weaken over time or after impact. Create adhesive application tool for assemblign the wing						
Wing Skeleton	Provide the wing shape, structural support for the wing skin, and contribute to	Fracture during impact.	Wing may not be reusable during testing.	3	High Impact Force.	4	Visual Inspection	2	**24**	Select a tougher wood or find a stronger material that doesn't increase the payload's						
Wing Skin	Produce lift during flight by lining the wing skeleton.	Skin tears upon landing.	Wing may not be reusable during testing.	3	Abbrasion or tearing due to warping of wing skeleton during impact	3	Wing skin currently made of visqueen, a light, durable plastic. Visual inspeciton and	2	**18**	Select wing materials that are abbrasion resistent and light. Design inspection						

Figure 44: DFMEA Analysis of IWD Samara Payload Body Sheet 2

File Organization

1. Problem Definition

Contains Problem Statement, Value Proposition, and Product Requirements documents.

2. Project Learning

Contains Snapshot 1 resources, initial research, and example videos of maple seed drops.

3. Project Management

Contains Administrative Resources, Team Budget, and Meeting Minutes (as well as meeting presentations and images).

4. Design Solution

Contains Design Review 2 and Snapshot 3 resources, Payload CAD files, and PCB components.

5. Implementation and Manufacturing

Contains PCB prototype guidelines as well as PCB design files for all versions.

6. Design Validation

Contains Design Review 2 and Snapshot 3 resources, as well as scale model drop testing.

7. Final Design Documentation

Contains Final Report, Final Presentation, and Engineering EXPO Resources (poster, slideshow).

8. Videos

Contains final assembly drop testing videos, and the laser cutting process.